HF RADAR TECHNOLOGY TRANSFER PROJECT - IMPLEMENTATION AND TESTING OF A TWO-SITE CAPABILITY

Kenneth A. Butt

Philip K. Jeans

Kenneth J. Hickey

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C-CORE

CENTRE FOR COLD OCEAN RESOURCES ENGINEERING
MEMORIAL UNIVERSITY OF NEWFOUNDLAND
ST. JOHN'S, NEWFOUNDLAND, CANADA, A1B 3X5
TELEX 016 4794 TELEPHONE (709) 737-8354

The Centre for Cold Ocean Resources Engineering (C-CORE) was established at Memorial University of Newfoundland in St. John's in 1975. Its initial funding was provided by the Devonian Group of Charitable Foundations of Calgary. Ongoing funding now comes from governments and industry.

The Centre's mandate is to undertake research that will assist the safe and orderly development of Canada's resources in cold and ice frequented oceans.

Kenneth A. Butt
Leader, Radar Group
C-CORE

(until June 1983 now with INSTRUMAR Ltd.)

Philip K. Jeans
Research Engineer
C-CORE

Kenneth J. Hickey
Computer Programmer
C-CORE

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ABSTRACT

A complete two station HF ground-wave radar has been acquired and fully tested at the Centre for Cold Ocean Resources Engineering (C-CORE). It is being used to gather oceanographic data and is called CODAR (Coastal Ocean Dynamics Application Radar). The present capability of the system allows the mapping of ocean currents from land based stations.

The system was tested in February 1983 at Cappahayden and Cape Race, Newfoundlanad. Some system specifications and a preliminary sample of the data analysis are provided.

Recommendations for improvements to the system and future work are outlined.

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1.0 INTRODUCTION

Recently a new remote sensing system called Coastal Ocean Dynamics Applications Radar (CODAR) has been developed for measuring ocean surface currents through Doppler processing of the high frequency (HF) surface wave backscatter from the ocean surface.

CODAR utilizes the 6 metre ocean wavelength which is one-half the electrical wavelength of the transmitted signal as a resonant structure satisfying the Bragg (first order) equation for scattering (Crombie, 1955). For any given ocean wavelength, the phase velocity of the approaching and receding wave can be analytically determined. Since Doppler frequency shift is a measure of velocity. it therefore can be shown that the Doppler frequency of the first order sea echo response is a measure of the phase velocity of the 6 metre ocean wave. We also know the transmitted wavelength; therefore we can calculate the expected Doppler response of the first order backscatter and thus assume that any difference in the measured first-order Doppler response is a measure of the near-surface currents running radial to the radar antenna. Although CODAR has been a National Oceanic and Atmospheric Administration (NOAA) development, the overall work on this technique to date has taken place in many international government and university laboratories (Barrick and Evans, 1976; Trizna et al., 1977; Shearman et al, 1979; SRI International, 1980 and Schirmer and Essen, 1980).

C-CORE. through its commitment to the development of Canadian cold ocean resources, initiated a program in 1981 to

acquire an expertise with the CODAR technology. Supported by the Department of Fisheries and Oceans, the Centre's intention is to develop this technology further to meet Canada's special needs for remote ocean monitoring of both ice and ocean environmental conditions.

1.1 Scope of Development

Initial efforts were focussed on the goal of acquiring a complete two-site operational CODAR (Butt and Jeans, 1981). However, it soon became clear that the Canadian offshore community was not ready to make the immediate financial commitment to such a new type of technology.

Meanwhile, C-CORE with its mandate to develop applied sea ice engineering together with Memorial University's Ocean Engineering Group initiated a concentrated research effort on the remote sensing of sea ice and icebergs at high frequencies (HF).

The dual potential application for sea ice and ocean variable remote sensing prompted C-CORE to purchase the necessary hardware for a one-site Doppler HF radar. The efforts of that acquisition program concentrated on assembling the hardware and on developing the computer software to form an operational Doppler radar for ice detection research and radial surface current mapping.

The acquisition phase was successfully completed in the spring of 1982 and is reported by Butt et al., (1983). Work continued throughout the summer of 1982 on developing a better understanding of the data interpretation process for current

mapping and preparing next winter's development pl s. By September, C-CORE was under contract to Supply and Services, Canada to implement and test a "two-site" current mapping capability.

1.2 Program Objectives

This next phase of the HF Radar Technology Transfer Project was supported primarily by Supply and Services, Canada under contract #0SS82-000 80. The program had the following objectives:

1. To complete a data reduction and analysis report on the operation of the single-site CODAR System.

2. To provide a detailed system engineering report for a two site current mapping radar.

3. To reconfigure the computer control to facilitate the "near" real-time production of current maps.

4. To complete the design for a portable high density radio telemetry link for high speed computer data communications. Emphasis will be placed on supporting a Canadian source for the hardware.

5. To develop a plan for a major offshore experiment for the late Spring of 1983. Emphasis will be placed on applying the CODAR system to investigate the forecasting of local iceberg movements as a portion of an iceberg countermeasures system.

This report reflects the work carried out to meet objectives 2, 3 and 4. Objective 1 is discussed under a separate report by Butt and Hickey (1983). Objective 5 was delivered as part of a

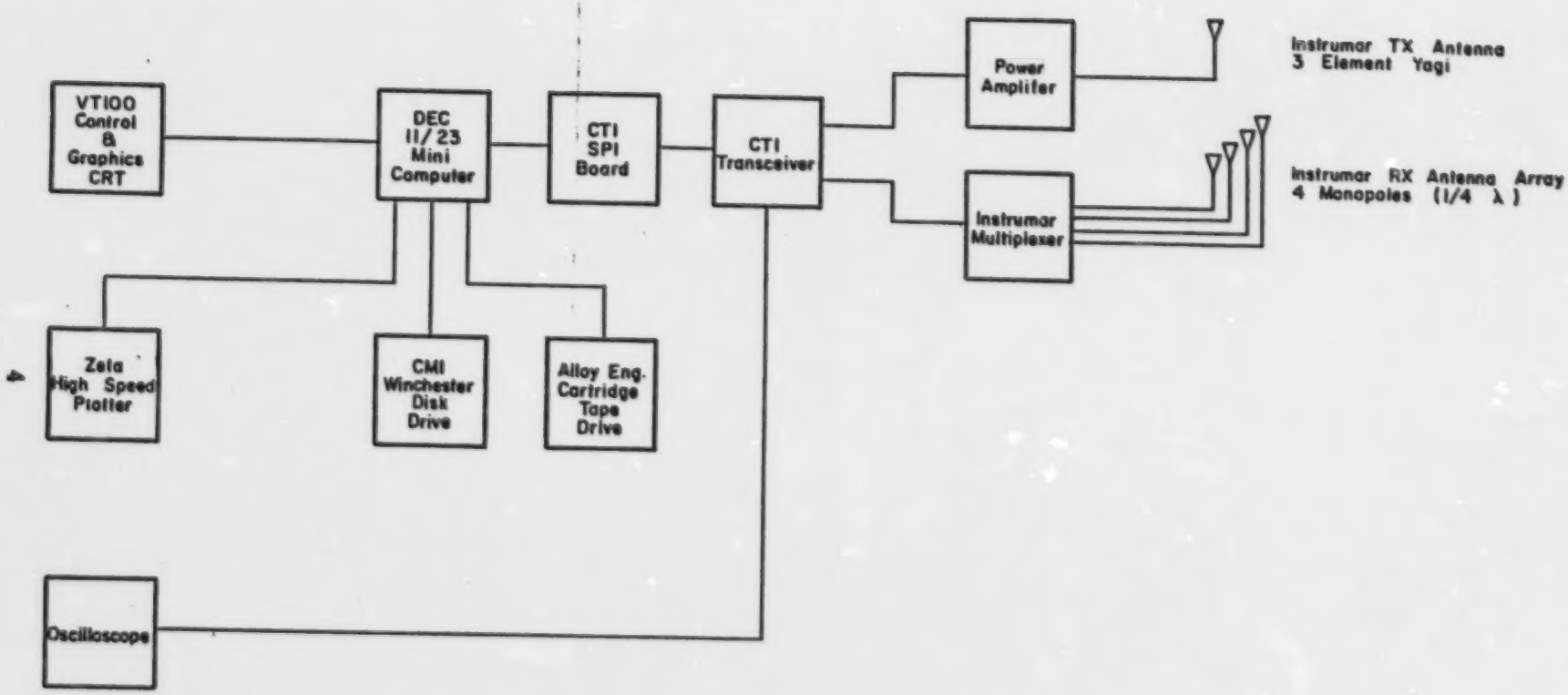


Figure 1 CODAR C-CORE System Block Diagram (1 of 2 stations)

comprehensive proposal to Mobil Oil Canada for an experiment in the Strait of Belle Isle, June, 1983.

2.0 HARDWARE ENGINEERING

A description of the CODAR hardware initially purchased by C-CORE is presented by Butt et al., (1983). This section contains an update to that description and concentrates on new developments. A complete set of detailed specifications are included in the Appendix of this report.

The present system is shown in a block diagram (Figure 1). C-CORE has to date one complete CODAR station. Two stations are required for generation of a complete current vector map and a telemetry link is required between the two for real time production of maps.

A full two station CODAR experiment was recently conducted by C-CORE using a second station leased for this purpose. A telemetry link was not used but a design has been completed. Further information on this experiment is presented in section 8.0. The following is a list of the relevant hardware developments that have occurred since March, 1982.

- Time multiplexing of the VT100 computer terminal for both control and graphics has been accomplished. A photo of this display, in use in the field, is shown in Figure 2. The combined plotting eliminates the need for a second terminal and should add greatly to the portability and realibility of the system.

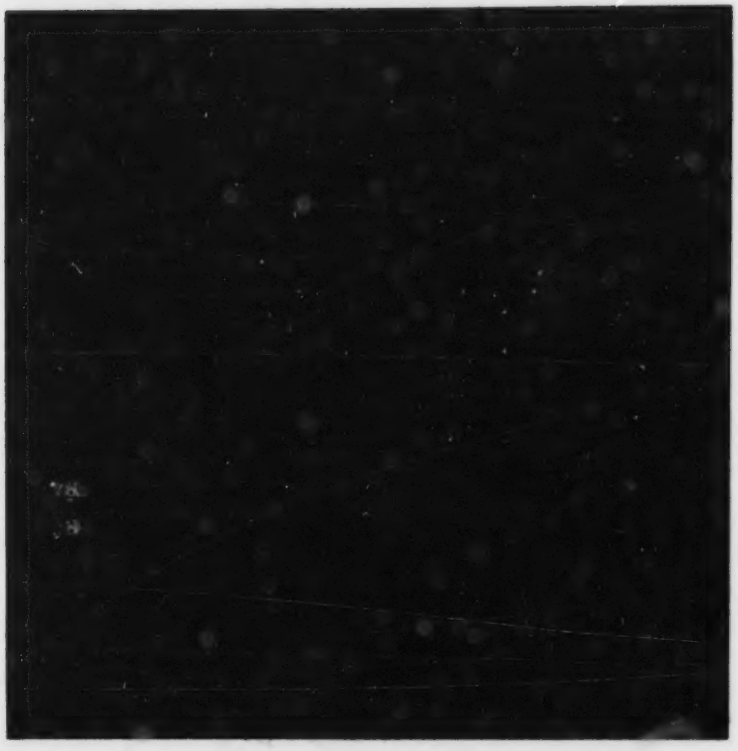


Figure 2 Photo of VT100 CODAR display console showing combined operations information with real-time spectral plotting

- The computer used its full memory capacity with the acquisition of a single "dual height" (256 k byte) memory board. This allowed implementation of NOAA's latest version of a disk-based data acquisition software system discussed in section 3.0.

- A "Winchester" disk drive was integrated into the system. A single drive can store up to 10.4 M bytes of formatted data and can be used for both data acquisition and data interpretation processes. It is preferred, over the previously used DEC RL/02 removable disk drive, for use in the field because of its higher durability, lower weight, smaller size and lower power consumption. See section 3.0 on the requirement for a disk drive in the field. The RL/02 disk drives, however, are an essential part of our CODAR laboratory system for storing large processed data files and system development. Their removable storage media and standardization make them effective for this use.

- A "cartridge" type magnetic tape drive has been integrated into the field system. One cartridge with a 137 m length of tape can store 44 M bytes of formatted data. It is preferred over a reel to reel tape drive because of its extreme ease of handling, lower weight, smaller size and lower power consumption. The Cypher reel to reel tape drive previously used in the field will still be used in the lab. The reasons are similar to those listed above for RL/02 disk drives. Reel to reel tapes are still the standard industry media for most scientific and commercial

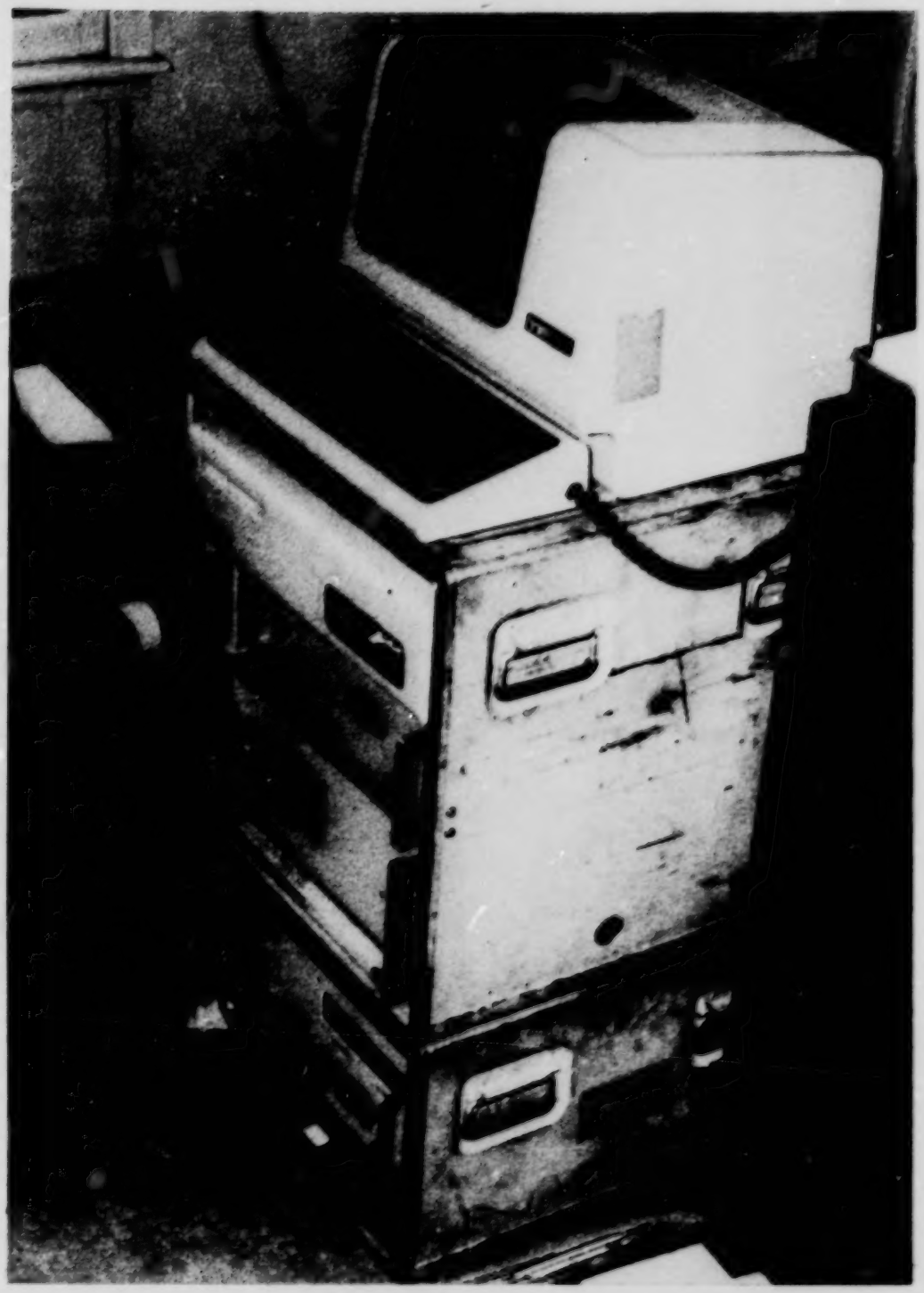


Figure 3 C-CORE's single site CODAR system less antenna system

information storage and exchange. They are also the cheapest mass storage media available to date.

- Both the Winchester disk drive and the cartridge tape drive have been integrated into a single package suitable for field operation. The package is 17.8 cm high and suitable for standard 48.3 cm wide rack mounting.

- Rigid antenna elements for the receive antenna array have been built to replace the very flexible fiberglass whips that have been used previously. They consist of hollow aluminum tubing as used in the elements of the transmit antenna. The purpose of this change was to investigate any possible Doppler contamination introduced by wind loading on the elements. A direct comparison of the two different elements is proposed for future tests.

- A second multiplexer box, transmit antenna, receive antenna array and their cabling have been acquired for a second CODAR station.

All of the above mentioned items have been successfully implemented and tested in the field during a recent two station CODAR operation discussed in section 8.0. Figure 3 shows a photo of C-CORE's single site CODAR station without the antenna system. The package as shown comprises the combined display terminal, central processor, sealed disk drive, high speed "cartridge" tape recorder, CTI transceiver and 10 kw power amplifier.

2.1 System Timing

This section provides information on the basic system hardware timing in order to clarify some of the operational aspects of the CODAR system. This is not an exhaustive analysis and is only intended as a rough guide.

The complete system timing of the CODAR system is based on an accurate temperature controlled 10 MHz crystal oscillator (TCXO) located on the reference oscillator board of the transceiver. All other frequencies in the radar except the computer and its peripherals are based on this frequency.

A series of frequency synthesizers inside the transceiver are used to generate the transmit frequency. They are all locked onto the above mentioned 10 MHz. The transmit frequency is software programmable and allows the selection of 20 frequencies from 25.00 MHz to 25.95 MHz in 50 kHz steps. The specific frequency of 25.40 MHz is most often quoted in this report and others as a basis for equipment specification. All of the transmit frequencies are equally valid and usable without any major retuning or recalibration of the system. Thus, the frequency selection can be made automatically by software control with no additional modifications to the power amplifier or antenna systems. The antenna systems were designed with a 1 MHz bandwidth so that the resulting parameter changes through that range are negligible. The transponder, however, requires the CODAR to be operated only at 25.40 MHz to suit its high resonance internal circuitry.

The receiver portion of the radar is phased locked to the same 10 MHz oscillator as the transmitter portion of the radar. This gives the system its coherent detection capability. It is of the superheterodyne type with three intermediate frequency stages. The incoming signal, after amplification and filtering, is converted first up to an intermediate frequency (IF) of 40 MHz by the use of a mixer, fed with a frequency ranging from 65.00 MHz to 65.95 MHz. The actual frequency depends on the transmit frequency in operation at the time. Thus, if the transmit frequency were 25.40 MHz, then it would be mixed with 65.40 MHz to convert the signal centre frequency up to 40 MHz. The reason for this up-conversion is to provide for a convenient frequency at which efficient crystal filters can be used. The next two IF stages are used to convert the filtered signal down to baseband or 0Hz centre frequency in steps rather than in one abrupt jump. Thus a reference of 37.5 MHz (fixed) and 2.5 MHz (fixed) are used to convert the signal down to a centre frequency of 2.5 MHz and then 0Hz respectively. The last stage of down-conversion also provides for in-phase and quadrature channels (I & Q) to retain the phase information of the signal. Thus a complex representation of the signal is formed that is treated as a phasor. By convention the in-phase channel produces the real part of the complex number and the quadrature channel produces the imaginary part. Each channel is sampled and then passed to a 12 bit analogue to digital convertor which produces an integer number in binary format suitable to be passed onto the computer via the signal processing interface (SPI) board.

The SPI board is essentially the radar system controller board. It is located in the computer chassis. Its basic timing is a 2 MHz clock supplied by the transciever. This 2 MHz clock is derived from the 10 MHz master reference by a divide by five circuit in the transceiver. The SPI board controls the transmit pulse width, the pulse repetition rate, the blanking, the gain and other controls of the transceiver. The pulse repetition frequency (PRF) is derived by dividing the 2 MHz clock on the SPI board by 1024 to give 1.953 kHz. This is fixed, and as noted above, is directly locked to the 10 MHz master reference. The total scan time (time between pulses) will then be $1/(1.953 \times 10^3) = 512$ sec. This determines the absolute range of the radar. The two way travel of the radar pulse (to and from the target) must occur within this period. Thus, given the velocity of an electromagnetic wave of 3×10^8 m/sec., the absolute maximum range to include two way travel time is calculated as

$$\frac{(512 \times 10^{-6}\text{s} \times 3 \times 10^8 \text{ m/sec.})}{2} = 76.8 \text{ km.}$$

Blanking actually reduces this figure by 2.4 km as no usable data is collected during the 16 μ sec period just before the transmit pulse is generated.

The pulse width of the radar is also software selectable via the SPI board and can be set at 8, 16, 24 or 32 μ sec. These pulse widths are also locked to the 2 MHz clock. They are generated by counting 16, 32, 48 and 64 clock pulses of the 2 MHz clock. (period = 500 n sec). This is also done on the SPI board.

The total scan time of 512 μ sec is divided up into 64 "range rings" of 8 μ sec. This again is done by counting periods of the 2 MHz clock on the SPI board. The SPI board sends a synchronizing signal to the transceiver every 8 μ sec. During each 8 μ sec period the following occurs;

1. The gain setting for the transceiver for the next 8 μ sec period is passed from the SPI board to the transceiver.
2. Operational status information on the transceiver is passed from the transceiver to the SPI board.
3. The I channel data (12 bit binary number) is passed from the transceiver to the SPI board.
4. The Q channel data (12 bit binary number) is passed from the transceiver to the SPI board.

The transfers above occur over a 12 bit bidirectional data bus between the transceiver and the computer where the SPI board is located. In addition to the data lines, 4 control lines are used to pass:

1. The 2 MHz clock from the transceiver to the SPI board.
2. A synchronizing signal every 8 μ sec. from the SPI board to the transceiver.
3. A transmit pulse corresponding to the width of the RF pulse.
4. A blanking pulse to the transceiver.

The above mentioned blanking or shutting off of the receiver occurs to protect the sensitive front end components from damage during transmission. The blanking occurs 16 μ sec. before a

transmit pulse. during the transmit pulse and 8 μ sec. after the transmit pulse. Thus if the transmit pulse were 8, 16, 24 or 32 sec. duration then the respective blanking periods would be 32, 40, 48 and 56 μsec. duration.

The gain of the receiver can be varied within a 100 dB (nominal) dynamic range in steps of approximately 0.4 dB. The gain is under complete computer control and is updated every 8 μsec. as mentioned above. The setting of the gain for each range is fixed for an entire data run. To date this has been done in a manual mode with the operator setting the gains just before a run. This is done by observing the analogue I and Q channel output during a test transmission.

Four receiving elements are sequentially sampled in a phase measuring array to perform the angle finding of the CODAR system (Butt and Jeans, 1981). Each antenna element is connected in turn to the transceiver via the multiplexer box. The first element is connected for 512 μ sec. It is then disconnected and the next element is connected. This occurs in a clockwise fashion during the entire data run for all four antennas. The samples (both I and Q) are buffered on the SPI board until 128 points (complex) per antenna per range are collected. Each of these 128 points is weighted by a data window stored on the SPI board and then averaged to give one 16 bit value. The actual resolution of the calculation is carried out to 32 bits on the SPI board but only the most significant 16 bits are kept. The only window that has been used at C-CORE to date has been a minimum 4 sample Blackman-Harris window. (Harris, 1978).

Averaging of the signal in this way produces a signal to noise voltage ratio of the square root of 128 or 21.1 dB (Trimble, 1968). Thus the sampling period of the resulting data stream for one range annulus for one antenna is 128 x 4 x 64 x 8 μ sec. = 0.262144 sec. ($2^{18}/10^6$). This is the sampling period that the computer "sees".

Fast Fourier Transforms (FFT's) are used extensively in the data interpretation phase of CODAR. A FFT is essentially a computationally efficient algorithm for calculating a discrete Fourier transform that is based upon the fact that the number of data points (complex) are an integer power of two. The CODAR software is set up, therefore, to collect only an integer power of two data points. Given the above mentioned sampling period of 0.262144 sec. the number of data points vs. the length of the data run (straight acquisition) is listed in Table 1.

TABLE 1. FFT Size/Time vs Data Quantity

NUMBER OF POINTS (complex)	LENGTH OF RUN (straight acquisition)	RAW DATA COLLECTED (1 station)
2^7 = 128	33.55 sec.	128 k bytes
2^8 = 256	1 min. 7.11 sec.	256 k bytes
2^9 = 512	2 min. 14.22 sec.	512 k bytes
2^{10} = 1024	4 min. 28.44 sec.	1024 k bytes
2^{11} = 2048	8 min. 56.87 sec.	2048 k bytes
2^{12} = 4096	17 min. 53.74 sec.	4096 k bytes
2^{13} = 8192	35 min. 47.48 sec.	8192 k bytes

The amount of raw data collected is based upon the fact that there are 2 channels per point, 2 bytes per channel (16 bits after SPI board averaging), 4 antennas and 64 range cells (annulus). The abbreviation "k bytes" stands for kilo bytes (1024 bytes). Recent software changes have allowed the operator the option of reducing the amount of raw data that is stored on tape by eliminating or dumping the data from extreme ranges that have been found to be too noisy for satisfactory data analysis. Also see the section on software for format of data storage and the implementation of pre-processing of the data.

The result of the FFT's are spectral pictures of the radar return for each range annulus for each antenna. Because of the nature of the sea return, we get a spectrum with both negative and positive Doppler shifts which are represented as negative and positive frequencies around 0 Hz. The reason for plotting both sides of the spectrum is that the return signal is not Hermitian. The signal is not duplicated exactly in the negative side of the spectrum. A Hermitian signal would give a mirror image of the positive side in the negative side. Most real signals encountered in signal processing are Hermitian which requires only the postive half of the spectrum to be plotted. The frequency range of the spectral picture plotted is the reciprocal of twice the sampling period = $\pm$ 1.907 Hz ($10^6/2^{19}$). Thus the spectrum will run from -1.907 Hz to +1.907 Hz regardless of the number of data points collected. The number of data points collected determines the resolution of the lines in the spectrum and is calculated as the total frequency range of 3.815 Hz

divided by the number of complex data points collected. Thus if 8192 points were collected then the frequency resolution would be 0.466 MHz ($10^6/2^{31}$).

A transponder is used with the CODAR system for checkout. calibration, data ground truthing and as a direct noise, bearing and velocity measurement tool. Its operation is described by Butt and Jeans (1981) and Evans et al., (1981). The present version of the transponder is limited by its circuitry to operate only at 25.40 MHz with a 16 μ sec pulse width. It has a fixed delay of 25 μsec. It locks onto the PRF of the radar using a phase-locked loop (PLL) and divides it by 2048 to get a 0.954 Hz reference ($10^6/2^{20}$). This reference is used to modulate the delayed pulse received from the radar to produce a double sideband (DSB) signal of 25.40 MHz $\pm$ 0.954 Hz. This pulse is then amplified up to 2 watts peak power (constant) and retransmitted back to the radar. The modulation forces the transponder return to show up in the spectrum outside the DC and sea state clutter.

2.2 Telemetry Hardware Design

This section describes a hardware design for a proposed telemetry link between two CODAR stations. Such a link is required to provide efficient coordination of the data acquisition and is vital to the production of two station current maps in the field. A discussion of the necessary software design and its operation is included in another section of this report.

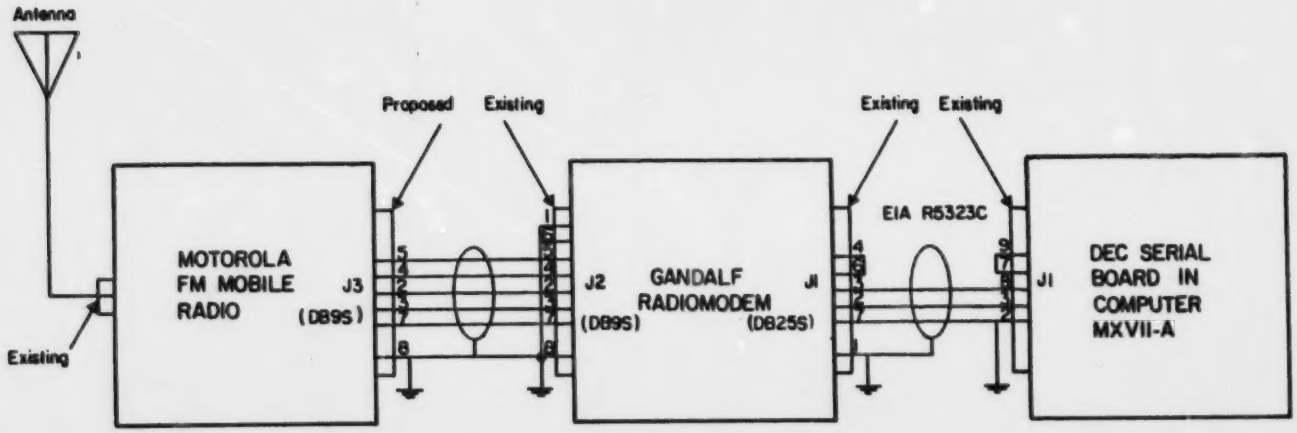
During the data acquisition phase of a CODAR run it is important to be able to coordinate both stations with respect to transmit frequencies, pulse width, length of data runs, time between runs and the start time of each run. While all of the above operating parameters may be pre-scheduled, varying weather conditions and logistics may cause abrupt replanning. Equipment malfunctions and site differences are also not precisely accounted for in operation. A voice link from an operator at one station to an operator at the second may resolve these problems quickly.

The production of a two station current map requires that the radial component maps from each station be combined at one station using vector addition to form a complete set of surface currents with magnitude and direction. (Butt and Jeans, 1981). The complete map is then displayed on an XY plotter at that same station. Thus the radial components and their locations must be transferred by telemetry link from one station to the next.

In the majority of sites proposed for CODAR operation a telephone link and thus a conventional telephone modem is unavailable.

The proposed design uses a recently available "modem" especially intended to be operated with a radio rather than a telephone channel. hence the model is designated as a radiomodem by its manufacturer, "Gandalf Data Communications Ltd." This "radiomodem" is hooked up to the computer in exactly the same fashion as an ordinary telephone modem and can be considered from the computer side of the link to operate exactly as if it were a telephone modem. A RS-232 link is made to a serial board in the computer from a standard connector (DB25S) on the radiomodem. (No acoustic link is used in any part of this telemetry design). The radiomodem is then connected to any of a number of commercially available FM mobile radios by another standard connector (DB9S) on the radiomodem. (This is shown in Figure 4).

The radio choosen for this design is a Syntor T43SRA manufactured by Motorola. In order to be able to use this radio with the radiomodem it must be modified as shown in Figure 5. The modification consists of interrupting two lines from the handset control and wiring the discriminator output of the receiver section to a connector (DB9S) to be mounted on the radio chassis. The two lines that must be interrupted or rerouted through the radiomodem are the audio input to the transmitter section and the push to talk (PTT) line that switches the radio from receive mode to transmit mode. The PTT usually operates a mechanical relay in order to provide this switching; however, some radios employ solid-state devices for this purpose. The entire hardware portion of this design requires only simple



RADIO J3 CONNECTOR

PIN FUNCTION
1. N.C.
2. PTT SWITCH OUT
3. PTT SWITCH IN
4. MIC IN
5. MIC OUT
6. N.C.
7. RECEIVE SIGNAL
8. RECEIVE SIGNAL RETURN
9. N.C.

MODEM J2 CONNECTOR

PIN FUNCTION
1. PTT RETURN
2. PTT SWITCH OUT
3. PTT SWITCH IN
4. MIC IN
5. MIC OUT
6. MIC RETURN
7. RECEIVE SIGNAL
8. RECEIVE SIGNAL RETURN
9. N.C.

MODEM J1 CONNECTOR

PIN FUNCTION
3. RCV DATA
2. XMIT DATA
7. SIGNAL GRD
1. PROTECTIVE GRD
4. REQUEST TO SEND
6. DATA SET READY
ALL OTHERS N.C.

SERIAL BOARD J1 CONNECTOR

PIN FUNCTION
8. RCV DATA
3. XMIT DATA
2. GRD
7. RCV DATA (-)
9. GRD
ALL OTHERS N.C.

Figure 4 CODAR Telemetry Design - Interconnection Diagram (Proposed)

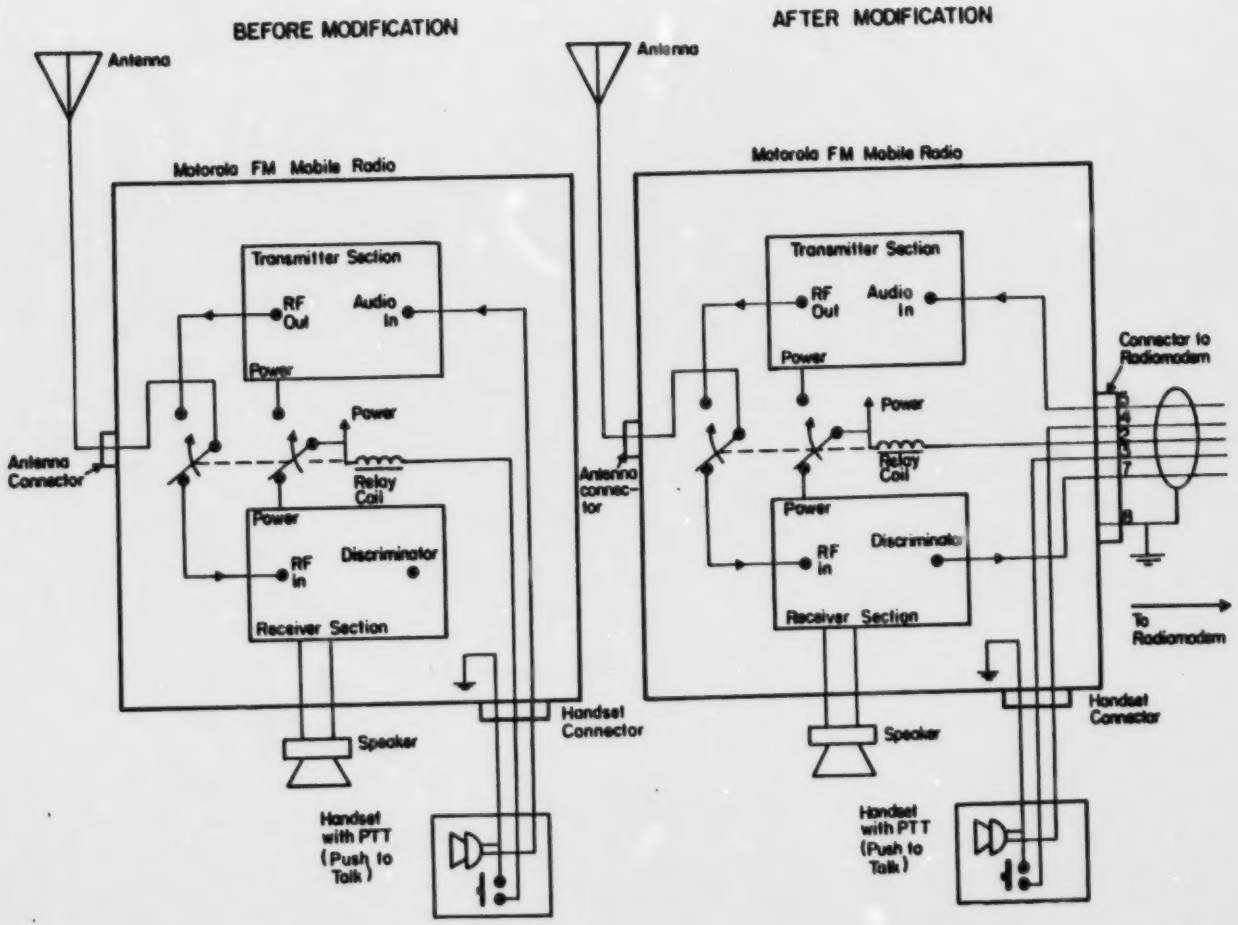


Figure 5 CODAR Telemetry Design - Radio Modification (Proposed)

wiring and installation of connectors. Some RF decoupling may be required to reduce noise produced from the effects of long leads.

The radiomodem contains a switch on its front panel that allows the operator to switch manually between voice and data. When the switch is set to the voice position, the radio is essentially disconnected from the radiomodem and the radio can be used as if no modification had taken place. This provides the essential voice link between the two CODAR systems. When the switch is set to the data position the voice channel is no longer connected and data can be transmitted through the radio via the radiomodem. The operator's microphone and PTT control (radio handset) are disconnected and the radiomodem performs the transmitter keying and supplies the transmitted audio signal (data).

Normal radio audio is always present at the radio speaker in both the voice and data mode. The operator may wish to turn down the volume of the radio when the radiomodem is in the data mode as the signal from the receiver will be unintelligible to the human operator.

The actual modulation produced by the radiomodem is not a frequency shift keying (FSK), as is often the case, but a proprietary encoding method used by Gandalf. The data speed can be set at 300, 1200 and 2400 bits/sec. asynchronous or 2400 or 3600 bits/sec. synchronous. The data speed selection is accomplished with a switch on the front panel of the radiomodem and pin strappings on the computer serial board. (MXVII-A)

Alternatively the baud rate clock may be wired from the radiomodem to the serial board to effect easier selection.

Directional antennas have been chosen to supplement the mobile radio whip antennas in areas of poor reception. The antenna choosen is a SINCLAIR model SRL-227 corner reflector with a nominal gain of 7 dB.

Earlier work on the telemetry design (Butt and Jeans, 1981) had concentrated on the use of relatively new digital modulation mobile radios. They did not require the use of any modem but did require more extensive engineering and testing. They could operate at a much higher baud rate (12,000 bits/sec.) and had a much lower bit error rate for a given signal to noise ratio. However. there were other drawbacks in addition to the extra engineering effort required. First, the "digital radios" were found to be much more expensive than the equivalent radiomodem and conventional mobile radio combined. Second, our existing computer (DEC 11/23) cannot fully utilize the fixed 12,000 bit/sec. data rate that the digital radio offered. The radiomodem has an adjustable rate. This offers control over the energy per bit transmitted and thus, over the signal to noise ratio of the signal. Thus, if an operator is experiencing unacceptable errors in a data transmission, he may be able to reduce the errors to an acceptable level by lowering the baud rate. The transmission would take longer but this is insignificant in this application. Also the radiomodem can be modified readily to be used as a telephone modem in addition to its normal mode of operation. This would be useful in sites that

offered the advantage of telephone lines. It would be impractical to modify a digital radio to operate over phone lines.

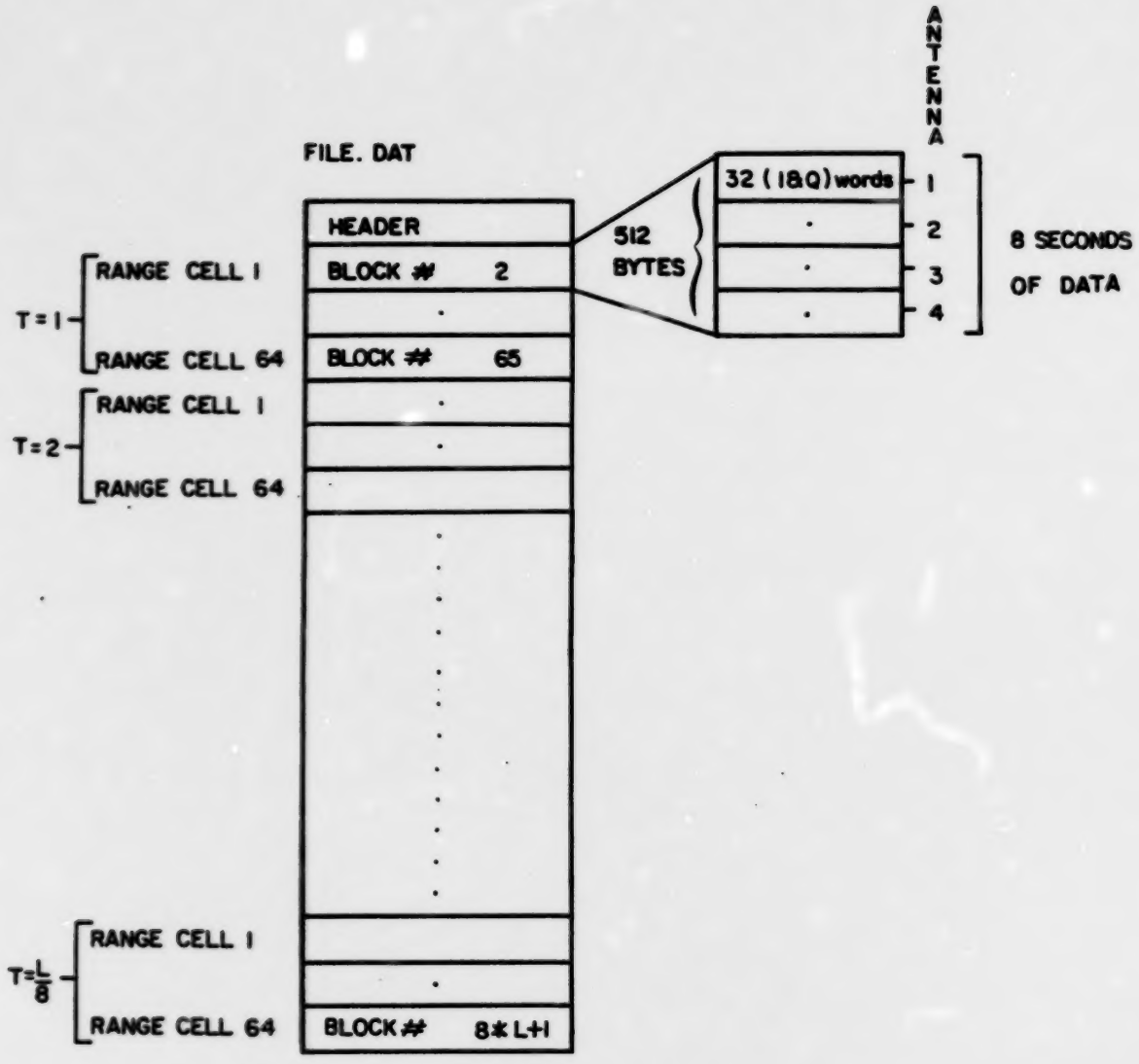
3.0 DISK-BASED DATA ACQUISITION SOFTWARE

Disk-based data acquisition software is the latest version of NOAA's system currently being implemented at C-CORE. The SPI/computer interface software is essentially the same as NOAA's original EMP version described by Butt et al., (1983). However, this is where the similarity ends. Instead of the unsorted time series data being stored on tape during a run, the new software directs the time series data to a file on disk. Upon run completion, a Fast Fourier Transform (FFT) can be performed efficiently on the time series per antenna per range cell using the random access capability of disk storage. The result is stored on tape in this processed format. This provides for a faster interpretation process as most of the data unscrambling and number crunching is done during data acquisition.

As well as the main components featured below, the new acquisition software package contains diagnostic, monitoring and updating routines to ensure an appropriate operator to machine communications interface. Since a full technical explanation of the software is unwarrented, only the program's main components will be dealt with in the following sections. Software processes are referenced with program code upper case type (eg: SETUP, DATA, etc.)..

SETUP

SETUP is the "doorway" to and from the CODAR system. Once the RSX11M operating system is up and running, a simple input of 'SUP' and a carriage return starts the CODAR system. All



L- LENGTH OF RUN (seconds)

T- # OF 8 SECOND SAMPLES NEEDED TO PRODUCE FILE

FIGURE 6 STRUCTURE OF TIME SERIES FILE

pertinent information is then displayed on the screen regarding user input (eg: site latitude, longitude, location, length of run, etc.). It is user interactive in that illegitimate input arguments are rejected and must be repeated. When all identifiers have been selected the operator has the option to diagnose, exit or continue with the CODAR operation.

CODAR

CODAR is the supervisor task for the system. It schedules all other tasks as needed. Task interaction and performance is also monitored by checking and updating flags in a region called COMMON. This storage region is simply a collection of variables that are "common" to most tasks (eg. Say the task PROC is processing a file of mini-time-series. When PROC is finished with this file, a flag is toggled in COMMON. CODAR checks this flag and if set, the time-series file is deleted. Using this principle CODAR keeps a running check on all of the activities of the acquisition software.)

DATA

This task performs the same function as EMP. It requests data from the SPI board, rearranges it such that it ends up in range cell major-order and then dumps its buffers to a disk file called FILE.DAT. This file is organized as a successive 8 second (32 sample Iand Q) mini-time-series. This organization, which permits direct data access, is shown in Figure 6.

DATA also passes I and Q time samples to the PLOT task where the output is displayed on a VT100 terminal either as a 32 sample time series or FFT depending on the choice of the operator.

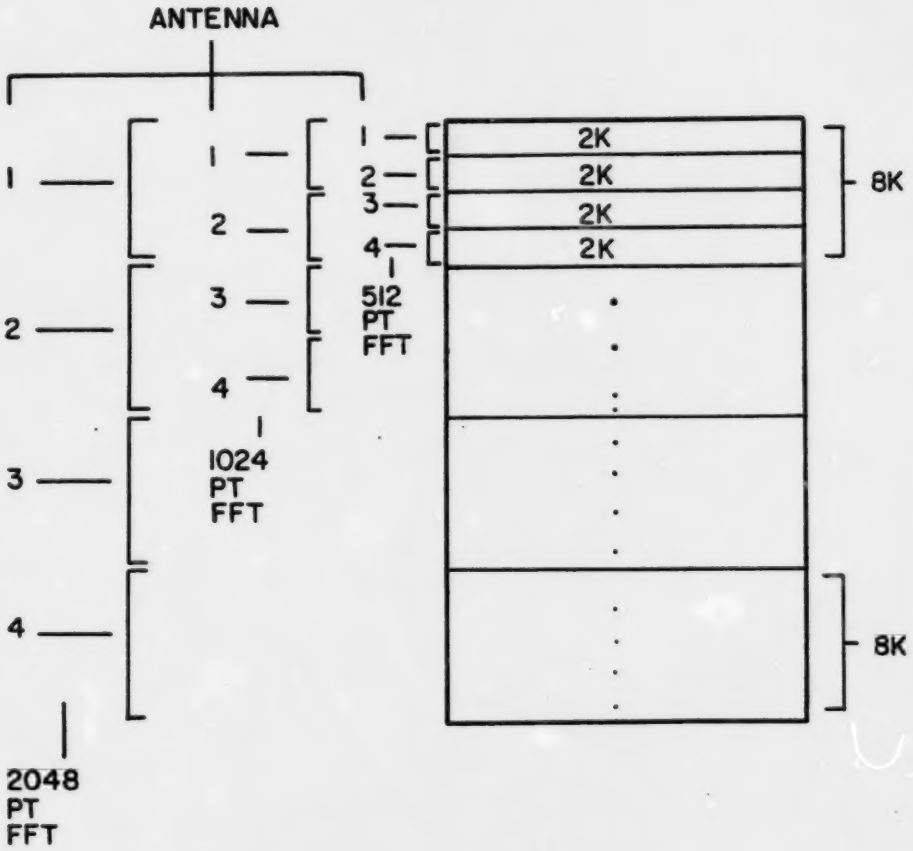


FIGURE 7 32K FFT-PROCESSING BUFFER

PROC

PROC takes over from DATA by unpacking the time-series contained in FILE.DAT. It then edits and detrends the time series, performs an integer FFT and writes the processed data to tape.

The FFT processing takes place in a 32K memory buffer as shown in Figure 7. This permits storage of all four antenna data simultaneously. An integer FFT is performed on each antenna segment of the buffer with the resulting transformed data occcupying the same space as the original time series. The buffer is then written to tape. All the range cells are processed sequentially in this fashion.

3.1 Software Changes

NOAA's disk-based acquisition system requires two terminals and two disk drives. Changes in C-CORE's version were required to reduce these to one terminal and one disk.

NOAA's first disk contains the system software while the other is used to store the time-series file. A 10 megabyte disk is sufficient space to handle our data processing requirements. The system software consumes approximately 5 megabytes while the largest time series file presently needs 2.5 megabytes. It was feasible, therefore, to use one disk for both functions. This involved the redirecting of all references to DL1* over to DL0*.

A two terminal system was also a drawback. One terminal was the operator interface to the system while the other acted as a simple plotting device for 32 sample FFT's and time series

displays. C-CORE's system terminal has plotting capability (SELENAR graphics board). It was desirable to keep our system compact and therefore incorporate the function of the slave device on the operator's terminal. This end was achieved eventually through extensive rewriting of the plot task. Access to the terminal for plotting could not interfere with monitoring displays on the screen. Further description of this work follows in section 6.0.

Another deviation from the original software involved changing the tape writing routine. Tape "writes" are performed as 8192 byte blocks. C-CORE's magnetic tape machine is a "streaming" cassette type drive with a maximum block size of 4096 bytes. A 2048 byte block size was all that was really necessary since a 512 point FFT requires 2048 bytes per antenna spectrum. A smaller block size could have been used but for programming ease a 2048 byte block was chosen. Retrieving the FFT's for post-spectral interpretation is then straight forward. The software change itself involved the segmenting of 8192 bytes into four 2048 byte blocks resulting in 4 tape "writes" instead of 1 per 8192 bytes of data.

* Pseudo names in software are needed to reference the hardware peripheral in question. DEC RL02's and their emulators (ie. Winchester disk drive, C-CORE's field system) are identified by the numonic 'DL' where 'DLO' is usually the system disk with 'DL1' ... 'DLN' being auxilary disks.

3.2 Comments

The disk-based acquisition system is quite an attractive setup in all respects. One terminal-operator interface permits total control of a one-site operation. An extensive user's manual is not required for system operation as most functions are performed in response to screen display commands. Once the main menu is displayed, programmed function keys direct the operator through setting up, error diagnosing, running and data monitoring of the CODAR system.

Some problems though, still remain. An automatic gain routine has been implemented. However, it does not yet work properly in the presence of heavy interference, so a manually set gain process (similar to the EMP version) is presently used. The present automatic gain algorithm is under development by both NOAA and C-CORE. Eventually it will play an increasing role in CODAR operation as longer unattended operations are required.

Another change to assist current map production in the field would involve the redirecting of the processed FFT's to disk and tape simultaneously. To facilitate post-spectral processing the FFT's have to be dumped to disk from tape to calculate the radial velocities and to produce a radial velocity file. As disk drive technology becomes more reliable for field operations, real-time processing with a memory-disk system can eventually replace most tape based operations. The tape drive would only be used as a backup device to store velocity files. Of course data collection operation is still possible in the case of a disk crash with a taped version of RSX11S, a bootable EMP and basic 11/23 memory.

PREORDER TREE TRANSVERSAL SUGGESTS FLOW OF CONTROL

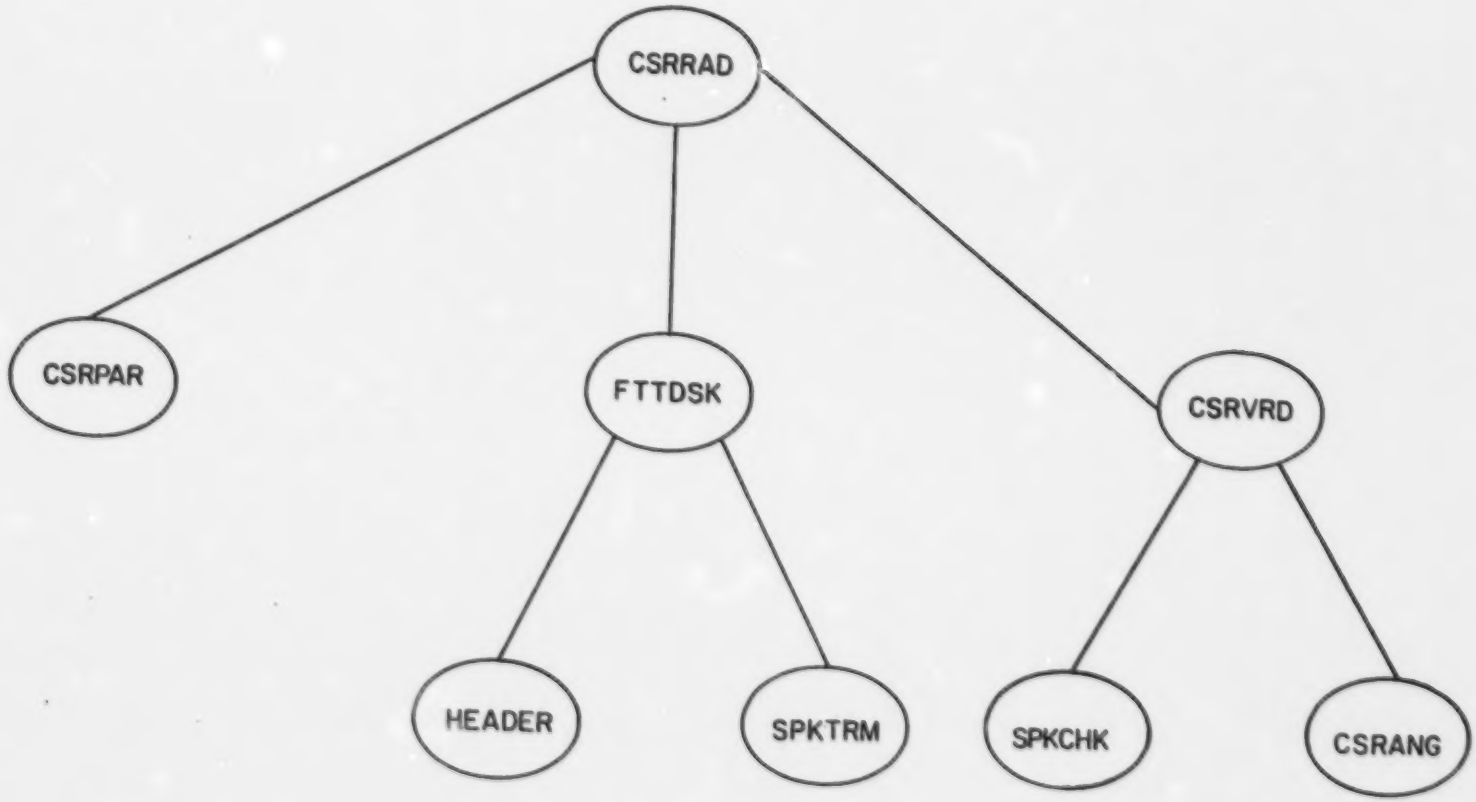


FIGURE 8 ONE-SITE DATA INTERPRETATION PROGRAM STRUCTURE

4.0 DATA INTERPRETATION SOFTWARE

The data interpretation software consists of two segments. The "one-site" interpretation segment produces a radial velocity file per site then a "two-site" segment combines the two radial velocity files to produce a vector surface current map.

Last year (1982), C-CORE implemented a one-site interpretation package based on software purchased by CTI. This implementation, although required to process data collected under EMP, is only needed in part for processing the data collected under disk-based acquisition. As discussed in section 3.0 each time series is presented and Fourier transformed before being dumped onto tape. Consequently, the processing time for the one-site software for 32 range cells has been reduced from approximately 90 minutes to 30 minutes for a 2048 pt. FFT. The following sections briefly describe the components of the revised one-site data interpretation package. Software processes are referenced with program code upper case type (eg: CSRRAD, CSRPAR etc.).

CSRRAD

This is the main program of the single-site data processing software. It calls the following program components. (REFER to Figure 8 for program structure.)

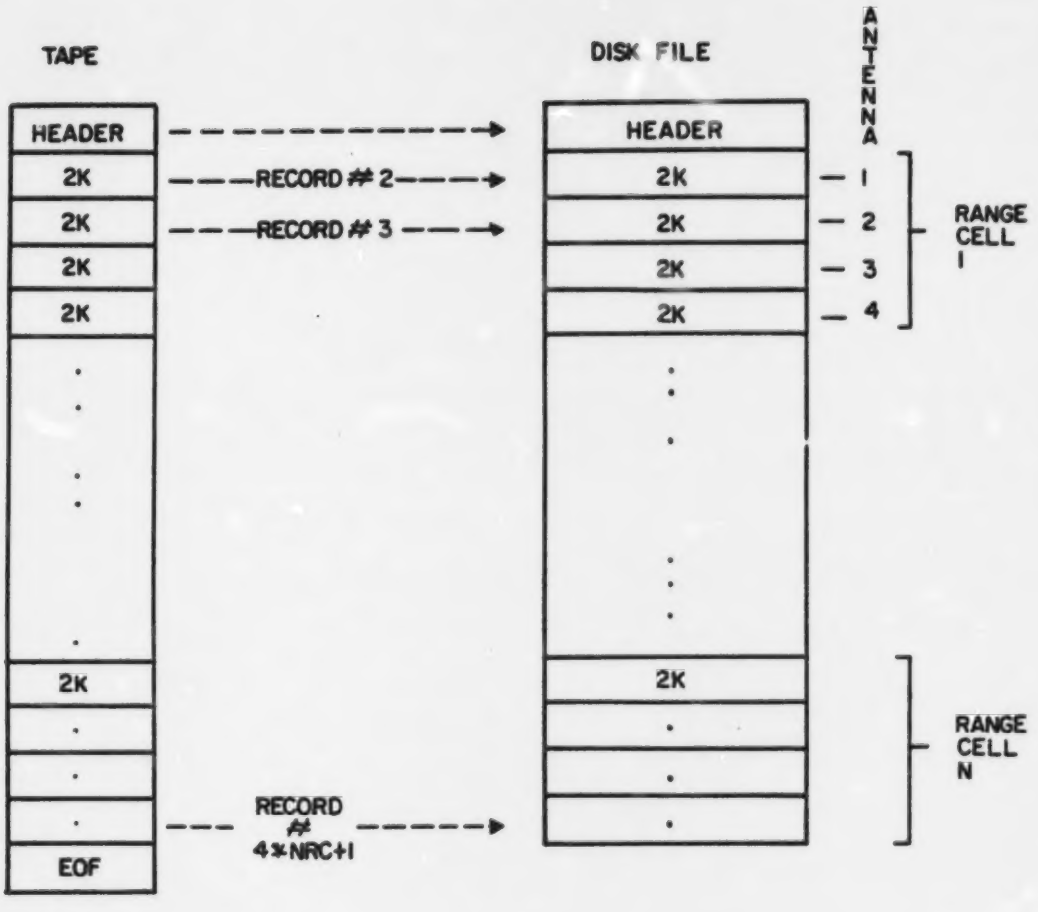


FIGURE 9 TAPE AND DISK FILE RECORD FORMAT FOR 512 PT. FFT.

CSRPAR

CSRPAR reads the necessary parameters such as FFT size, antenna separation, starting and stopping range cells etc., from a file called CSRRAD.PAR.

FFTDSK

This routine dumps the FFT's from tape to disk in range cell major order. An example of the tape and disk format is shown in Figure 9. It also passes control to the following two subroutines.

HEADER

Information read from the header of the disk file is used to calculate the Bragg frequency, the window limits to place on the spectra for surface current measurements, etc.

SPKTRM

SPKTRM performs power calculations on the spectral data and saves the average power computed from an assumed first order area and a 'noise' region. For surface current computation this noise region is composed of all points not within the first order area. These averages are saved in a COMMON region to be used by the radial processing routine CSRVRD.

CSRVRD

This routine computes the radial current velocity as a function of range and angle using the following steps:

1. Four FFT's are read from disk (one for each antenna) and the first order window ranges are stored a 4-dimensional temporary array.

2. A subroutine called SPKCHK determines if the spectra is good enough for processing by checking the output of SPKTRM for the current range cell.

3. Radial velocities and corresponding angles of arrival (CSRANG) are computed from the Bragg sea-echo sidebands.

4. The preceeding steps are performed serially for all range cells.

4.1 Software Changes

This software package was based on CTI's interpretation software for EMP produced tape output. Certain segments were deleted such as the time series to disk routine as well as the FFT processing.

The magnetic tape processing routines also had to be deleted and replaced by similar programs using RSX-11M operating system functions. CTI have written their own magnetic tape routines that are considerably faster than those of RSX-11M but purchasing those was not justifiable since a totally disk-based system is utilized; tape output speed is a secondary concern.

A major space saving technique has been implemented. Since integer FFT's instead of complex FFT's are used, all routines that processed large complex arrays (large with respect to the operating space of the LSI 11/23) were modified to handle their integer counterpart. (ie. a 4096 point complex FFT needs 32 K of

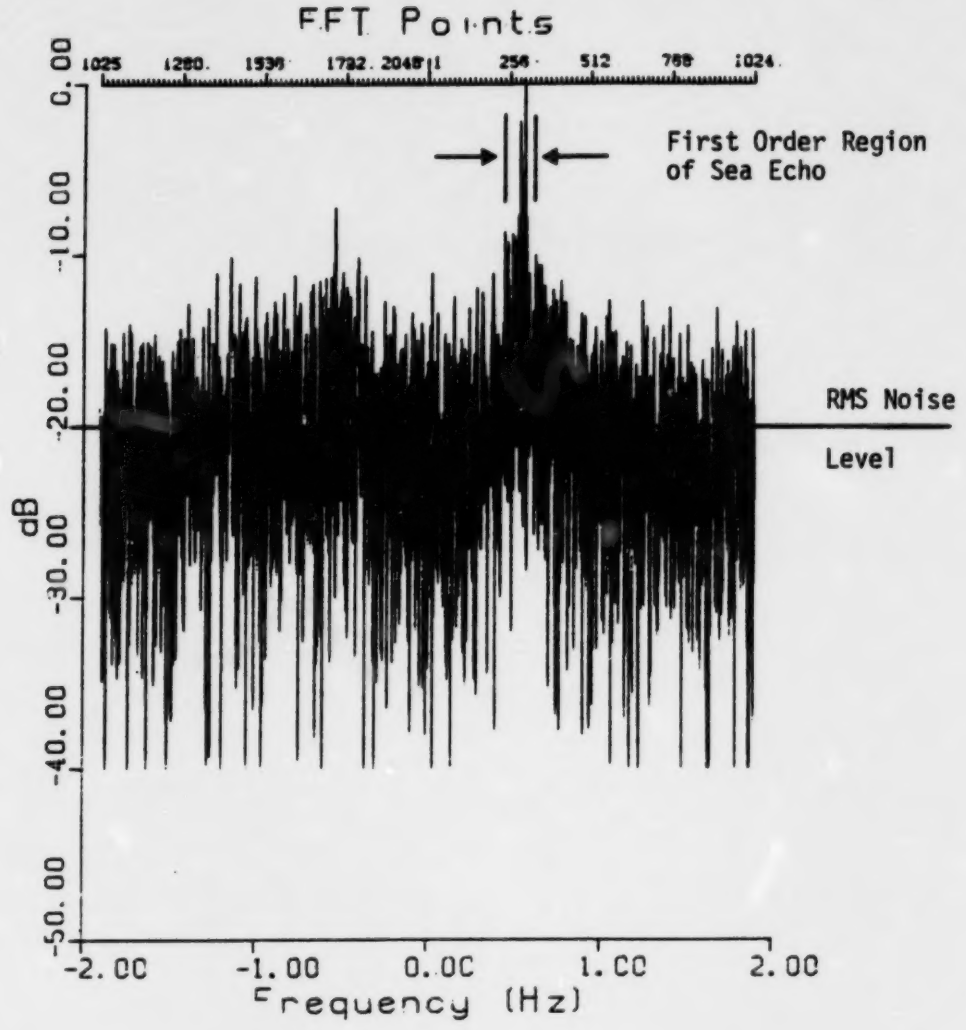
memory for processing while a 4096 point integer FFT requires 16K.) The N/2 reduction in space could lead to a totally memory resident interpretation software package if small FFT's (1024 point) are acceptable.

4.2 Comments

The structure and function of the one-site interpretation software is evolving into an efficient FORTRAN package. However, certain components are questionable as far as algorithm correctness is concerned.

The spectrum checking program that decides whether the spectra are 'good' or 'bad' will reject data as presented in Figure 10 even though useful first order surface current information is often still present in the spectra. As was mentioned earlier. SPKTRM computes two averages with their difference determining what part of the spectrum will be processed to extract radial velocities. The problem lies largely with the determination of proper window limits to compute these averages. Weaker second order return is often included with the first order window region. This can lead to a false value for signal thresholding. A better estimate of the spectral quality can be achieved by using a similar algorithm where the window limits can adapt to varying spectral power.

Another problem lies in the calculation of the radial velocities themselves. The window limits of the first order region are presently chosen based on an assumed limit for the maximum radial velocity component. These limits are constant for



Antenna: 1 Range Cells: 25
Run Time: 23-FEB-82 11:24
Latitude: 46 51 40
Longitude: -52 56 45
Antenna Boresight: 112.00
Frequency (MHz): 25.40
Pulse Width (us): 16.00
FFT Size (points): 2048

Figure 10 Doppler spectrum showing useful first-order region data often rejected through inadequate regional power to total noise power ratio processing

all range cells processed. Hence, second order sea echos are often processed as if they were legitimate first order returns. Proper windowing algorithms will have to be implemented to ensure that an appropriate domain is used to compute the radial velocities. Algorithms for this purpose have been developed at C-CORE but have yet to be applied. If implementation proves successful many empirical parameters associated with the processing can be deleted.

4.3 Two-Site Vector Map Software

Currently the two-site software is composed of two separate programs. CSRCUR produces a file of current vectors while CSRMAP plots the vector map on a ZETA plotter. The following sections will explain the program flow:

CSRCUR

CSRCUR generates three subprograms to produce a file of current vectors. They are as follows:

CURPAR

CURPAR reads from a disk file called CURPAR.PAR input parameters such as the names of the two radial files, the name of the output file, grid information, etc.

DATFIL

DATFIL checks the validity of the two input files by checking site locations, run times etc. to ensure that the correct input files were chosen. If header information is destroyed or inaccurate this checking can be overridden by simply setting the appropriate variable in the parameter file.

CURGRD

CURGRD produces a vector file by performing data quality checking calculations (CURDAT) and vector derivations (CURVEC) from the two radial vector files.

Each vector component is generated based on the average of the velocity components within a specified radius "X" (kilometres). Any vectors "N" standard deviations away from the mean are rejected and a new mean is calculated with the remaining vectors. The parameters "X" and "N" are input from CURPAR.PAR.

CSRMAP

This is the main program that plots a surface current map from the file output of CSRCUR. It reads user input from a file called CSRMAP.PAR such as scale information, map rotation, etc.

Appropriate literals are then displayed on the plotter page regarding site information, run time, vector and map scales as well as a coastline plot. Control is then passed to MAPVEC and a grid of surface current vectors are plotted.

4.3.1 Comments

The only modifications required to the two-site software from CTI were those changes necessary to make it compatible with C-CORE's ZETA high speed plotter.

Complete analysis of the software has yet to be undertaken regarding performance but a minimum upper bound on the required time to run CSRCUR and CSRMAP is approximately 10 minutes to produce a 625 point (1.2 km spacing) map. This approximation is based on in-house usage and will vary slightly with grid size requirements, vector spacing and vector averaging required.

It is intended that some form of hard copy plotting will be done in the field. Present thoughts are focussed on the SELANAR

graphics already present on the field terminal. It is feasible to plot a current map on the VT100 CRT without major modifications to the existing software package. A raster scan plotter can then be used to produce hard copy in a few seconds. A major criticism of this technique is the 240 line vertical resolution of the SELANAR graphics, and inherently the VT100 itself. However. it should be pointed out that rarely will a complete scaled map be displayed for purposes other than gross process flow analysis. More precise scientific objectivity can come from expanded zone displays.

5.0 RADIO PERIPHERAL INTERCHANGE PROGRAM (RIP)

RIP or Radio PIP, (Radio Peripheral Interchange Program), is a program written at CONFORMATION INC., to carry out file transfers between two PDP-11 computers. As the name indicates its primary function is the same as the standard DEC PIP program, but this utility program was primarily intended to operate between two remote sites via a radio modem. It will also functon with a telephone modem, or a directly connected null modem cable. To transfer files one needs at least two RS-232 terminal lines on each computer. One should be attached to a terminal where the user will input the commands, and the other should be attached to the modem link.

Both PDP-11 computers should be running the RSX-11M operating system, version 3.2 or 4.0. The program RIP.MAC and command file RIPBLD.CMD should both be resident on a privileged UIC. The user should log on to this UIC and run the command file, which will then assemble and build the RIP task. Once it is ready to go one runs RIP and is ready to transfer files.

5.1 Function

Immediately after it is started, RIP prints a warning message on the user's terminal reminding him to set up one terminal line as a slave line for use with the modem. The program then prompts the user for a command. After the user inputs a command it is checked for syntax, then parsed to determine what the command is and finally checked to see if it is a valid command.

If it is a valid transmit file command, the program determines whether the specified file name is valid, then it attempts to find it on the device specified; this defaults to the system disk if one is not specified. If the file exists, it is opened in preparation for transmission. If an incorrect file name is specified or the file cannot be found an error message is printed and RIP exits to MCR.

The transmit RIP prepares for the transfer by sending a synchronizing message to the receive site. Next, it gets notification that the receive site is ready to go. The transmit site then sends the file name to the receive site which opens it and then proceeds to transfer 128 byte blocks of file data, one block at a time, via the modem link.

Once the end of file (EOF) marker has been transmitted, the file at the receive site is closed. The receive site will remain in the receive mode until RIP is aborted. The transmit site remains in the transmit mode, prompting for the next command. Thus one could transmit a whole series of files by typing in the transmit commands one after the other.

RIP was also written so that it can be controlled by a command file. This means that one can predefine a sequence of instructions to compile, build, and run RIP. One may then have it transfer a series of files from the transmit site up to the receive site and turn itself off once it's finished. Thus by setting up the appropriate command files and supervisor task, one could send a given set of files to another site anytime a certain set of conditions were met, while an equivalent task at the

receiving site could be ready to accept and store these same files, entirely without operator intervention at either site.

5.2 Evaluation

In the test of the RIP software, communication was established between C-CORE's LSI-11/23 computer, with a Winchester disk drive and "cartridge" tape drive, and Memorial University's Engineering Faculty's PDP-11/70 computer. C-CORE's machine was running RSX-11M version 3.2 and the 11/70 was running RSX-11M version 4.0. RIP was installed on the 11/70 from a 9-track FLX tape, and on the 11/23 from the same tape via C-CORE's Cipher Micro streamer 9-track drive. After extracting the appropriate files from the RIP Library module on the tape we used the supplied command file to assemble and task build the RIP program. Initially, we could not install or run the resultant task on the 11/70 system because we were logged onto a non-privileged account. This was changed and we were able to run RIP successfully.

We then transferred Fortran, Macro and data files back and forth between the two computers. The files all appeared to go through without error. The computers were linked by a null modem cable attached to the "slaved" port of each computer. The transfer speed over a 9600 baud serial line was about 256 bytes per second, or 1/2 a disc block per second. In addition to the actual data transfer time there is about another 20 seconds involved for establishing contact between the two computers and sending the file name of the first file to be transmitted.

The software worked reliably during our short test and appeared to transfer data at an acceptable rate. During a field experiment however the speed of transmission between sites would be somewhat less than 9600 baud, thus cutting the data rate proportionately.

Operation of RIP in the field for data transfer between two sites can be used immediately in its simplest manual form. To extend the operation of the program to communicate automatically between two unmanned sites or an unmanned remote site and a manned site. a small amount of straight forward software would have to be written.

5.3 Summary of RIP

RIP is a straight forward utility program, easily implemented on any PDP-11 computer with:

- RSX-11M operating system. version 3.2 or 4.0
- two terminal lines one for the console and one for the modem
- a communication type hardware modem

In its present configuration RIP can transfer data files between two operator controlled sites. It will also support command file usage, which could allow automatic control under a supervisor program. Given some extra programs which could control the transmission sequence, RIP would be suitable for unmanned CODAR operations.

RIP is just software and thus its transmission speed is limited by the communication hardware used. Given a reasonably

fast data link, this software should be able to transfer data at the rates previously discussed in Section 2.2.

RIP is an acceptable program for transferring CODAR data files from the remote CODAR site to the central site for processing.

6.0 SINGLE TERMINAL PLOTTING DEVELOPMENT

This section describes the software patches and programs added to and removed from the basic NOAA Data Acquisition software distribution kit described in Section 3.0. It outlines what changes were required, the reasons for these changes and describes the limitations and design criteria which these changes had to fit. The alternate methods for making these changes are discussed briefly, followed by our reasons for choosing a particular method.

6.1 Preliminary

Throughout the following sections, the plot and console devices and plot and console tasks are used to describe the following two functions of the Data Acquisition package.

The CONSOL task is responsible for interrogating the user for the necessary header and timing information for running and identifying each data acqusition run. It prompts for information on the user identification, the run identification, starting time and run interval. It also allows the user to alter the transmission frequency and pulse width, as well as various other run time parameters. CONSOL also displays and updates these

parameters and provides clock displays of the time, the time to the next run, the time left in the run, the operational status of the system, and if they occur. error messages. The console device refers to the terminal, where the user inputs and the programs output the various bits of information previously discussed.

The PLOT task provides real time plots of information being recorded by the DATA task. The user can select either a time series from the I or Q channel, or a short FFT of the data. In the latter case the PLOT task calls on the following two tasks. FFT task creates the FFT from the time series. PROC task edits and detrends the result. The data for the plot, whether time series or FFT is then scaled for display and sent to the plotting device. The plotting device in NOAA's case is a special Hewlett Packard graphics display and custom interface. C-CORE on the other hand, uses a Selenar G-100 graphics board as part of the VT-100 terminal control console.

With this brief introduction to the functions of the two tasks and some knowledge of the RSX-11M operating system the reader should have a better understanding of the implementation problems and solutions described in the following sections.

6.2 Problem Definition

The new NOAA Data Acquisition System written by the NOAA/CONFORMATION group as it was distributed had two major problems for the C-CORE program. First, it was written to work with specialized graphics hardware for the display of plots and

plot information in real-time and second, the C-CORE program was focussing on using a single terminal for both the display of real-time plots and the regular console information.

The two main requirements were to:

1) Rewrite the NOAA software to work with our graphics hardware.

2) Rewrite the software so that both console and plot information could be displayed on a single terminal.

6.3 Design Criteria

The following is a list of the six major points which have to be met by any software patches or new software.

1) Software must be able to plot PLOT Task output on C-CORE's Selenar G-100 graphics board.

2) Software must put both console and plot information on a single VT-100/Selenar Graphics board combination.

3) The new software must fit within the 32K work task limits of the DEC operating system.

4) The new software cannot interfere with the data acquisition part of the system.

5) The combined console and plot information must be displayed in a readable format.

6) The changes should not add any complications to running the field system.

These six requirements were the major design goals and limiting factors involved in making software changes and/or additions to the Data Acquisition package.

6.4 Alternate Solutions

The tasks to be changed were PLOT and CONSOL. Figure 11 shows the basic arrangement of the software and hardware.

The first step is to integrate the two devices, console and plot, to a single terminal. To do this it must be noted that the plot task needs be active only during a data acquisition run. Thus to synchronize the two tasks, a patch must be made in the CONSOL task, in a portion of the program where it will be executed continually during a run. This patch must be made to establish some kind of synchronization between tasks. As both tasks are executing simultaneously, they could conceivably attempt to write data to the single terminal at the same time.

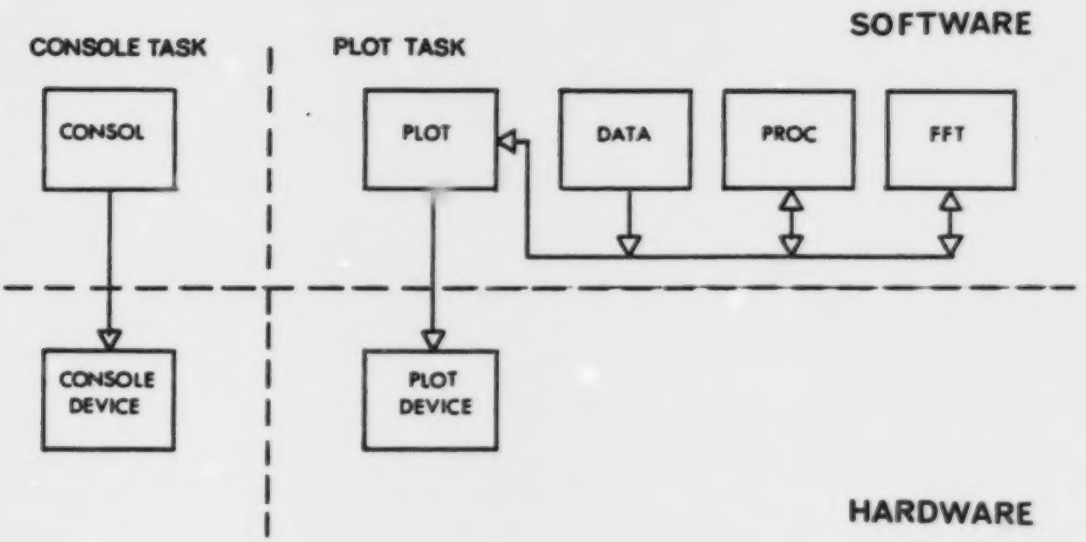


Figure 11 NOAA CODAR Display System

This would probably cause one or other of the tasks to "crash". Some handshaking communication had to be established which would allow the two tasks to multiplex the use of the terminal. Thus, some point in both routines had to be found in which to place these hand shaking patches.

The CONSOL task is made up of twelve modules. Each module is responsible for some part of the tasks function. Several of the modules have subroutines which output information, to take information from, or monitor for unsolicited input on the console device. There is no single routine or module responsible for I/O operation with the console device. The module CONUPD or CONsole UPDate however. is a focal point through which the task always passes. It acts as a dispatcher for all the various terminal I/O routines. This offers a point in the console routines where any program patch we need to make will be in the main loop of the CONSOL task execution during the data acquisition phase.

In PLOT, the flow of the program is less contorted than in CONSOL. PLOT is a straight line program. It acquires the data, processes it, then plots it. The logical place for the synchronizing patch is then, just before PLOT task attempts to output to the terminal.

The locations for the synchronizing patches in the two tasks had now been identified. The next step was to determine what changes in the plotting software had to be made to make it work with C-CORE's Selenar graphics instead of NOAA's graphic device. As it turned out, the changes needed were for the most part in the actual command string sequences sent to the plotting device.

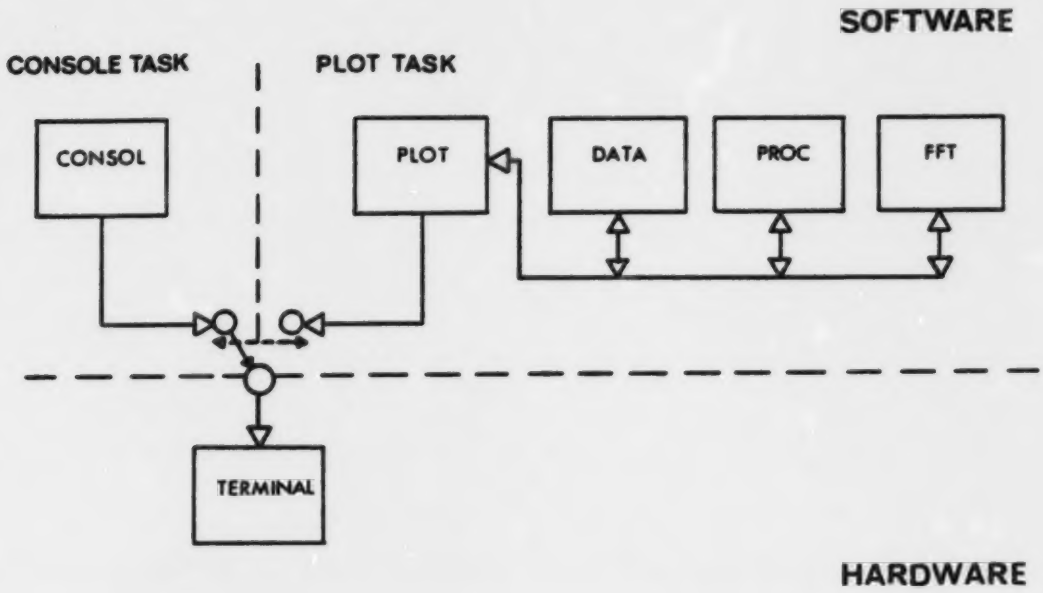


Figure 12 Proposed C-CORE Display - Alternative 1

The main flow and logic of the existing plot software could stay intact.

Various alternative ways of carrying out the final solution were examined. Two routes were highlighted.

Alternative One (see Figure 12) would keep the original NOAA logic arrangement almost intact. The major difference would be the handshaking patches used as a software switch between the two tasks. The PLOT and CONSOL tasks would multiplex the use of the single terminal between them.

Alternative Two (see Figure 13), would change things quite a bit. In this route, the PLOT task would acquire the data and process it into a plot ready form, as well as making up the plot

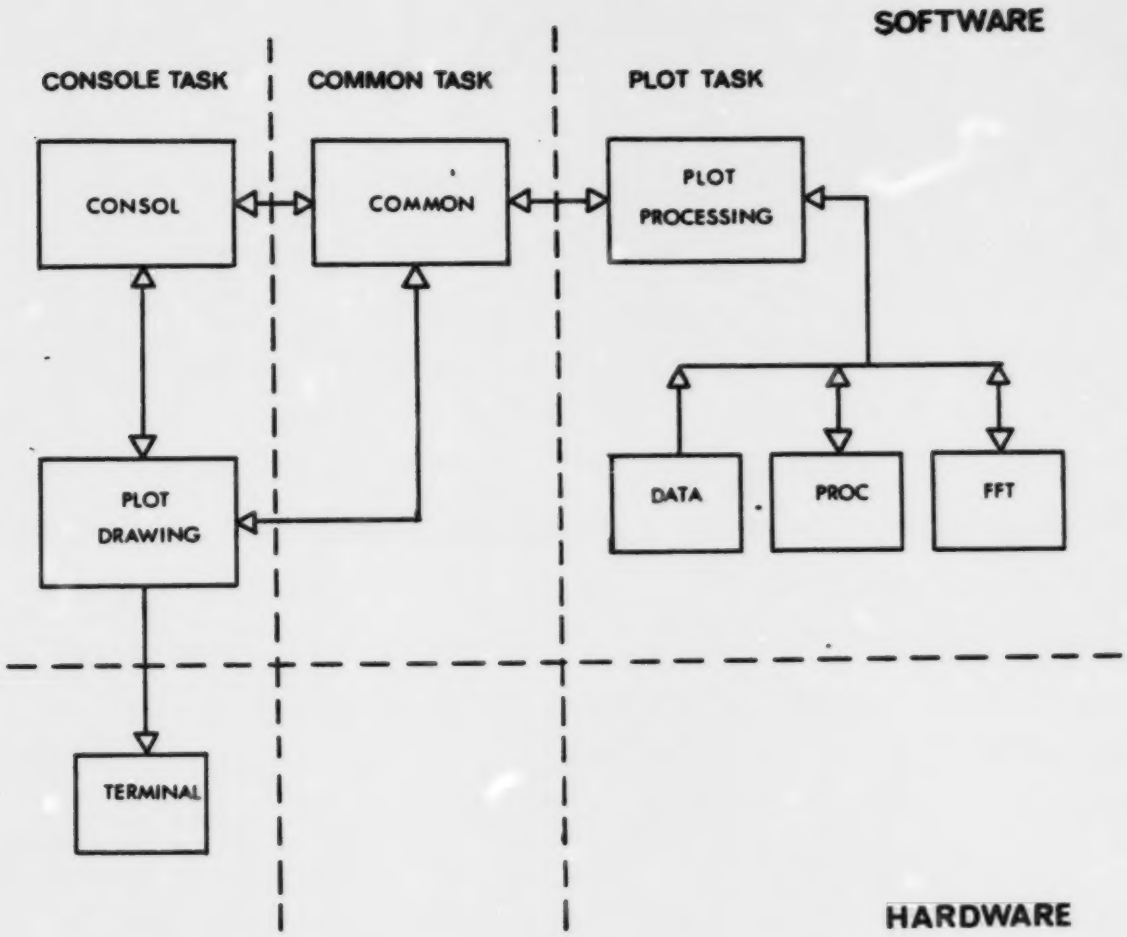


Figure 13 Proposed C-CORE Display - Alternative 2 (Final Configuration)

header information. All of this data would be stored in the COMMON task. PLOT would then tell CONSOL that a plot was ready. CONSOL would see the flag and run a new module which would retrieve the data from COMMON and plot it. CONSOL would then tell PLOT to fetch another plot.

6.5 Selection

Both alternatives met all the criteria. Both would use a single terminal for both plot and console devices. The PLOT task, the section that actually talks to the terminal, would be changed to output the appropriate Selenar command sequences. Both CONSOL and PLOT had enough room left in their memory segments to allow either alternative to be implemented. Because both routes would not change the logic of the tasks significantly or interfere with the tasks' system parameters, such as priority, neither would interfere with the data acquisition portion of the system. The new plotting program could use portions of the console screen that were not presently used, thus allowing integration of the plot information with the console information without changing the console routines.

Alternative One was chosen because there were no apparent system dependent reasons why it should not work. It would require fewer logic changes and would not require any major changes to the COMMON task.

IMPLEMENTATION

Rewriting the plotting software in the PLOT task was the first job to be tackled. It was a larger job than we anticipated. Significant contract time was needed for rewriting and changing before the final four program form was reached.

Next, a short length program was patched into the CONUPD program to monitor two flags in COMMON. One flag would indicate when PLOT wanted the terminal and another to tell PLOT it could

have it. With the addition to two short programs to help carry out the above functions, the modified package was ready for debugging.

After several weeks of debugging, rewriting and testing, the first integrated test was made. It failed! The two tasks would not share the same terminal. This appears to be a DEC "system" oriented problem. Alternative Two now was not far away. The changes necessary to transform Alternative One working software to fit Alternative Two were minimal and straight forward. Rather than pursue the "system" operational solution, with a degree of uncertainty, Alternative Two was approached; three weeks later it was up and running in its final form.

7.0 COMMENTS ON CODAR DIRECTION FINDING

The direction finding technique of C-CORE's present CODAR system consists of a four element phase measuring antenna array used in conjunction with an algorithm implemented in software. This section contains a brief discussion of this technique and outlines areas of possible improvement.

The only direction finding technique that C-CORE has implemented has been to use the above-mentioned array and a combination of both a single and double angle of arrival algorithm. The array and processing software were first designed by NOAA and since 1977 have been successfully applied by them in a variety of oceanographic experiments (Weber and Leise, 1982). The designated name of the software is "CSRANG.FTN"; the last modification was by B.L. Weber on Dec. 1, 1978. A West German HF Radar group under the direction of Dr. F. Schirmer of Hamburg University have been using a slightly modified version of this same software for current mapping off the German Bight and Baltic Sea.

The antenna array is described in detail by Butt and Jeans (1981). The classification "phase measuring array", should not be confused with the much more common classification of a "phased array". The classification depends not so much on the physical layout of the array itself but on the way in which the array is used. The four element square configuration presently being used is an extension of the two element interferometer used by Crombie (1955) and others. Extensions to higher numbers of elements have been studied and applied by Moody (1980) using somewhat different

techniques. He gives a set of solutions that solve for N angles of arrival requiring 2N uniformly spaced elements. His solutions are nonlinear and are not closed form for 2N greater than 4.

The terms "single angle" and "double angle" refer to the number of angles of arrival the respective algorithms can resolve as an estimate of the real signal or signals incident upon the antenna array. It is important to note that while only one or two signals are resolved by the direction finding algorithms for each Doppler frequency, there are up to hundreds of these "cells" being examined for each transformed time series. Each cell within the estimated region of the first order return is examined. Thus hundreds of signals can be resolved for one range annulus. The final output for one range annulus is a plot of radial current vs. azimuthal angle. All of the direction finding used with CODAR, that can be found in the literature, models the return signal as having zero elevation angle. This is entirely consistent with CODAR's ground-wave nature. In addition to the one or two angles of arrival, the algorithms also return an estimate of the signal(s) amplitude and phase (relative to the centre of the array) including a "quality figure" or estimate of how well the signal(s) have been recovered.

A detailed description of the two angle algorithm is given by Weber and Leise (1982). It consists of a closed form solution of four complex simultaneous nonlinear equations. These same equations can be rewritten, for the sake of clarity, as a set of eight simple (non-complex) equations by breaking up the complex equations into real and imaginary parts. Then the number of

unknowns can be specified as eight. This is true if one considers the fact that one needs both an estimate of the sine and the cosine of the angles of arrival to resolve direction over 360° (Butt and Jeans, 1981). The solution thus indicates that the equations are of an exactly determined nature (neglecting noise).

There are several singularities involved in the two angle algorithm and these are clearly listed by Weber and Leise (1982). The nature of these singularities allow for their detection and alternate solution except when two signals have exactly the same absolute phase at the centre of the array. This condition is independent of the angles of arrival of the two signals. It is, however, statistically very unlikely and is assumed to be insignificant in practice. No detrimental effects on a data set, that could be attributed to this condition, have been observed at C-CORE. None have been described in the literature on CODAR. Further investigation into this condition will attempt to quantify its statistics.

The most important singularity in the two angle algorithm occurs when there is only one angle of arrival corresponding to only one plane wave incident on the receive antenna array at a specified frequency. This is detected in the software and a switch is made to a single angle algorithm. The single angle algorithm is quite simple compared to the double angle algorithm; it is an overdetermined system of eight nonlinear equations. A detailed description of this solution is given by Leise (in press).

The decision to use either a single angle or a double angle solution is made by the software based upon the data itself. Recent work at NOAA has centred on carrying this principle one step further. In a "hybrid" approach to the problem both a single and a double angle solution are found and then a decision is made to accept either one or the other based on "quality factors" calculated for each solution. This eliminates the need to set a tolerance value in the software to detect the singularity caused by a single angle. A tolerance value is used as a threshold below which a variable is deemed effectively to be zero but is actually some small value due to noise. Thus a singularity which causes some variable to go close, but not entirely to zero, can be flagged by this method. Setting of the tolerance values has proven to be difficult and at present there does not seem to be a precise way of doing this. The hybrid approach appears promising and is under investigation at C-CORE.

In a simple current flow area it would seem that only a single angle algorithm would be required. However, the effect of noise can be equivalent to some single spurious signal (Weber and Leise, 1982). This has also been observed at C-CORE. All of the above mentioned direction finding techniques work quite well when there is little or no noise. If simulated signals without noise were used to test them, there would be no way of evaluating which would be more effective with a real signal that is contaminated with noise. A good example of this can be observed in the case of a single angle algorithm that uses only the phases of the voltages on the four antennas. It is a trivial solution and can

be derived readily. When no noise is present it gives an exact solution; with noise it gives wildly varying results. Noise can be defined, in communications theory, as any unwanted signal which can be random or non-random. In analyzing first order sea return the noise can be ambient or higher order sea return or a combination of both. Thus even when the "signal" appears to be 20 dB or more above the noise floor, it may have a signal to noise ratio of much less. The signal in this case is superimposed on a pedestal of unwanted signal.

The single angle solution (part of CSRANG.FTN) used at C-CORE uses both the amplitudes and the phases of the voltages. It is not nearly as sensitive to noise as the solution that uses only phase. It is, however, sensitive to antenna gain imbalance unlike the solution that uses just phase. If no noise were present as described by Leise (in press) then even extreme gain imbalance would produce insignificant error. The two angle solution requires both amplitudes and phases of the voltage to produce a solution even with no noise. It is more sensitive to antenna gain imbalance. It has been found at C-CORE that the balancing of the antennas plays a critical role in the direction finding; the gain correction factors cannot be found as readily as first seems apparent. Comparisons of the spectral energy for each antenna for one range, does not always produce reliable gain corrections. Investigation is underway to evaluate the averaging of the antenna imbalance across range cells. Thus the gain corrections would be calculated from an entire run rather than just one range.

TABLE 2

	ACTUAL		MEASURED						
RUN NUMBER	RANGE CELL	BEARING T	RANGE CELL	BEARING T			BEARING T		SNR(DB)
				ADVANCING DOPPLER	RECEDING DOPPLER	MEAN	STANDARD DEVIATION	ERROR ACTUAL MEAN	
1		359*	12	355	355				40
			13	355	355				40
			14	354	354				35
			15	356	356				30
				357	357				25
				351	351	355	0.6	4	20
2		134**	4	131	129				30
			5	129	130				35
			6	130	130				35
			7	130	130				30
			8	130	129	130	0.2	4	25
3		116**	5	116	116				40
			6	116	116				40
			7	116	116				35
			8	117	116				30
			9	116	115				20
			10	115	114	116	0.2	0	20

* - Measured by magnetic compass.
** - Measured by transit.

TABLE 2. Results of Transponder texts used to confirm operational status of CODAR four element direction funding technique.

NOTE: These results were obtained from 128 second runs. Longer runs were performed per transponder position with similar results as the above. They were not included in this table since the statistical results as shown would not be affected.

A "quality factor" (Weber and Leise, 1982) has been used to give a measure of confidence to the signal's estimated angle of arrival. It is a comparison of the sum of the square of the sine of the angle and the square of the cosine of the angle with unity. (The sine and cosine are calculated somewhat independently in each solution). Meanwhile, the effectiveness of this quality factor is being questioned. It has been found that for some situations it does not agree with known signals. In several cases when a transponder and a two signal algorithm were used, the quality factor favoured a random signal direction over the primary transponder signal direction which was also returned by the algorithm to better than 4°, in the worst case. The results of this experiment are summarized in Table 2. Meanwhile, better accuracy and repeatability are observed by using a two angle rather than a single angle algorithm in the above mentioned cases. This is not what one would have reasoned intuitively before the data was analyzed. However, it is possible that the additional signal could be the result of multi-path propagation of the transponder return. This does not, however, explain why the algorithm favoured the weaker signal.

A promising solution to the estimate of signal confidence is to use a "match factor", rather than the above mentioned quality factor. In a least square solution of a set of simultaneous equations an effort is made to minimize the sum of the squares of the residue. The residue is simply the difference between what the original voltages were and what they would have been, assuming the solution was correct. Thus an estimated signal

composed of angle of arrival, magnitude and phase would be used to calculate 4 new antenna voltages to compare against the original voltages. The comparison or "match" can then be expressed in decibels as a type of signal to noise ratio (actually an estimated signal to residue ratio). This procedure has been partially tested on the previously presented transponder returns and gives quite promising results. It consistently favoured the true transponder return over the secondary noise signal. Further work will be done to test the match factor with sea return.

Recent work by Lipa and Barrick (1983) has produced impressive least-squares methods for the extraction of surface currents using both the four element array mentioned above and a crossed-loop/monopole antenna system. The crossed-loop/monopole can be added to C-CORE's existing CODAR system with virtually no other hardware change. It also has the advantage of being able to monitor the waveheight directional spectrum from the second order sea return as well as ocean currents. The concept relies on forming and scanning a beam electronically rather than direction finding as discussed above. C-CORE hopes to investigate this technique further during the coming year.

8.0 TWO-SITE EXPERIMENT

C-CORE'S first experiments at Cappahayden was logistically simple (Butt & Hickey, 1983) allowing close attention to be paid to the fundamental system performance. With this thought in mind, we hoped to include Cappahayden in this year's "two-site" CODAR experiment. This allowed us to use a site from which we had previously collected good data.

The greatest restriction to establishing a two-site mapping experiment with our present equipment is the need for both sites to be accessible by truck, close to the shoreline and between 20 to 30 km apart. (Butt and Jeans, 1981). We were in luck. The Canadian Coast Guard operate a manned light house approximately 23 km south of Cappahayden, at Cape Race. C-CORE was given access to this facility which included accommodation for two researchers. Both sites could provide an ideal vantage of the Ballard Bank (see Figure 14).

Initially, our largest concern with using Cape Race was the fear of having the long narrow dirt road to the site becoming blocked by snow. As it happened, this winter was milder than usual on the Avalon Peninsula. However, northern Newfoundland and Labrador had an exceptionally long period of sea ice growing conditions this year which produced a new problem for us. The two-site experiment was scheduled for February 21. Conditions off Newfoundland's south/coast by this time were showing how effective the south flowing Labrador current was in bringing down the northern ice.

Dispite severe ice conditions we went ahead with our

Figure 14 Map showing location of Ballard Bank

experiment as scheduled. A northwesterly wind was being predicted, which would assist the tides in keeping the ice far enough offshore for our experiment. This indeed was the case and we were successful in collecting two-site data, every hour on the half-hour. for a 26 consecutive hour period. Although the common area of two-site coverage was never totally ice free, there were periods when 30 km ranges were achieved. We believe overall that the collection period was fortuitous; it provided us with HF backscatter data over several classes of Labrador pack ice for future examination.

8.1 Peliminary Analysis

First attempts to process C-CORE's February 1982 data for single-site analysis indentified a host of systematic parameters needed at various stages of current map production. Several man-months were subsequently spent on developing a better understanding of how each would affect the final product. Those parameters which appear of most significance are: 1) the specified dimensions of the first order Doppler window for any given range cell; 2) the calculated signal energy to noise threshold for signal quality rejection; and finally 3) the decision of whether to use single angle or multiple angle of arrival direction finding.

All of these points were mentioned throughout this report in one form or another. A recent report by Liese (1983) discusses most of these issues in detail.

It is still clear that operational experience is desired for

the production of accurate current maps. Meanwhile, the present processing package can produce a useful product in turn-key fashion.

The first results of our two-site data collection are exemplified in Figure 15. The data was not carefully windowed for first-order returns and without filtering shows higher vector variability than the filtered result depicted in Figure 16. The filtering discussed here is basically a statistical process applied to each grid point where the vector at that point is influenced by the current vectors surrounding it. The filter area (see section 4.3) was choosen with a 5 km radius for the results presented here. Figure 17 and 18 show the hour before and after that of the period shown in Figure 16.

For the moment these results can only be discussed in a qualitative fashion but as processing continues, the entire data set will eventually be examined for mean, tidal and residual constituents as an extension of the first single-site data analysis (Butt and Hickey, in press). Meanwhile, it is worth noting the position of the edge of the Ballard Bank (shown by the solid line in Figure 16) and the surface flow pattern which attempts to follow it. The evidence is not as strong in either Figure 17 or 18. However, as CODAR essentially maps only the top 2 metres of ocean current, this is not an unreasonable response.

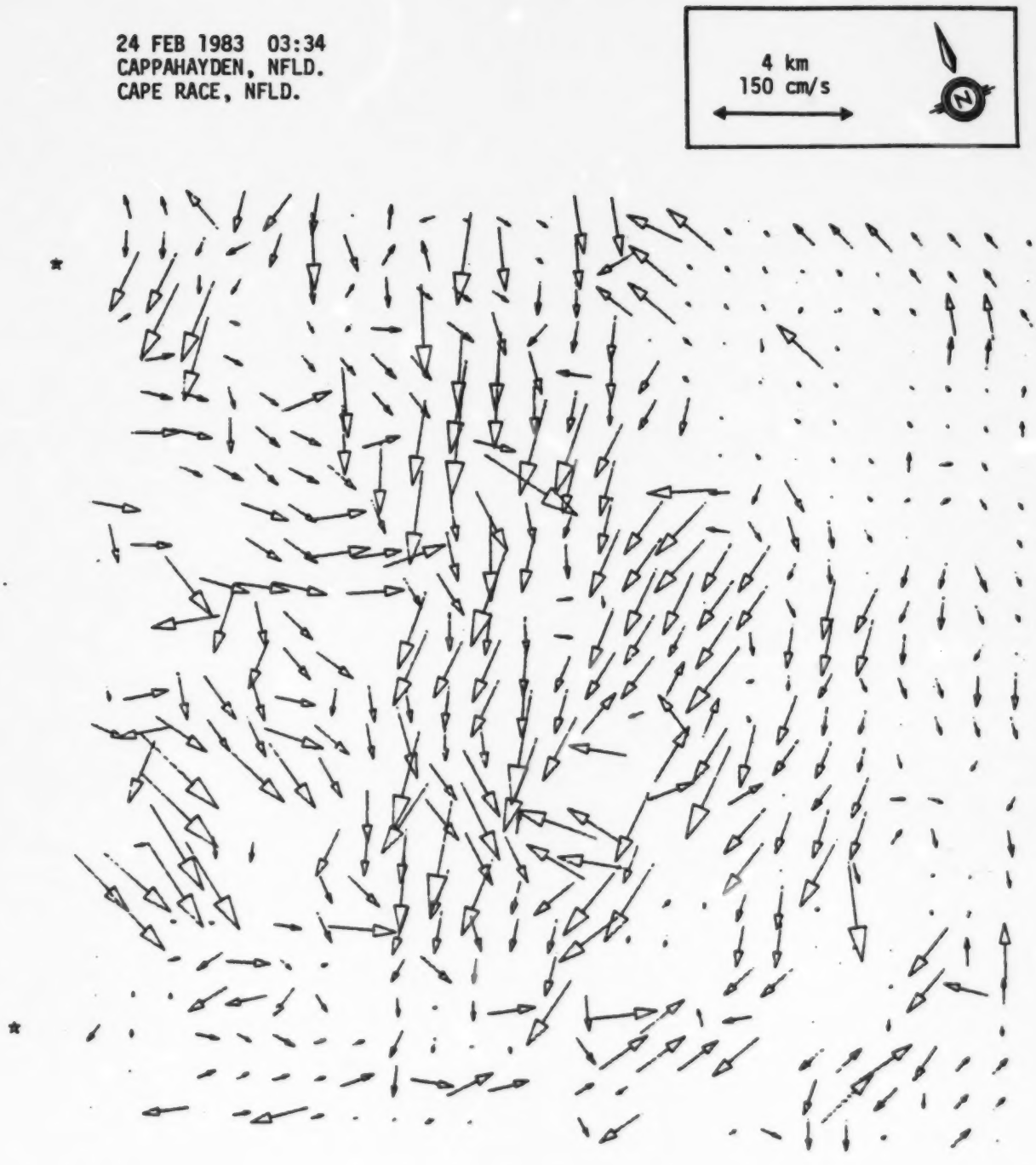


Figure 15 Surface current map produced by two-site CODAR, February 1983 without windowing for first order and no statistical filter applied

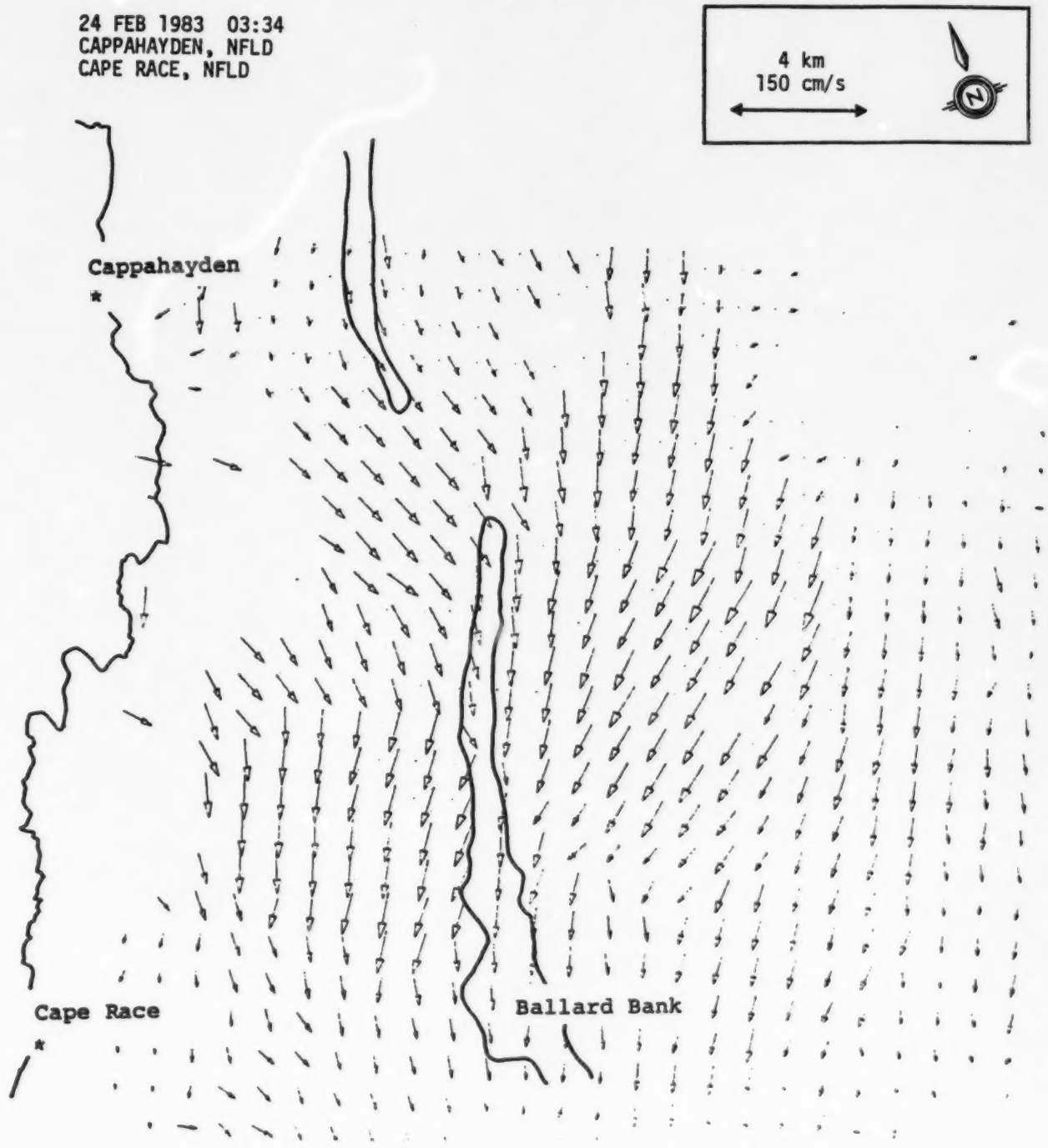


Figure 16 Surface current map produced by two-site CODAR, February 1983

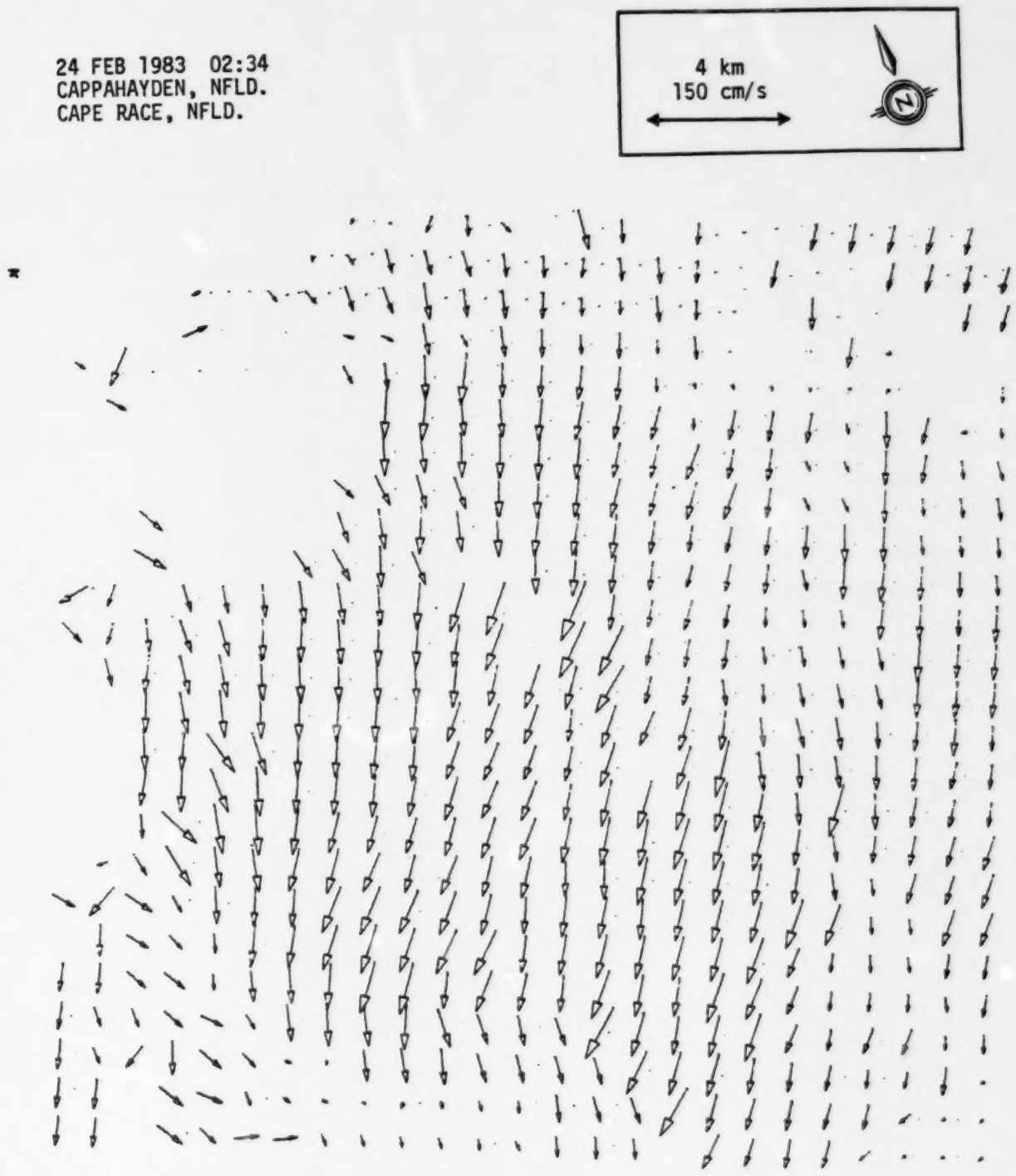


Figure 17 Same as Figure 15 but one hour earlier

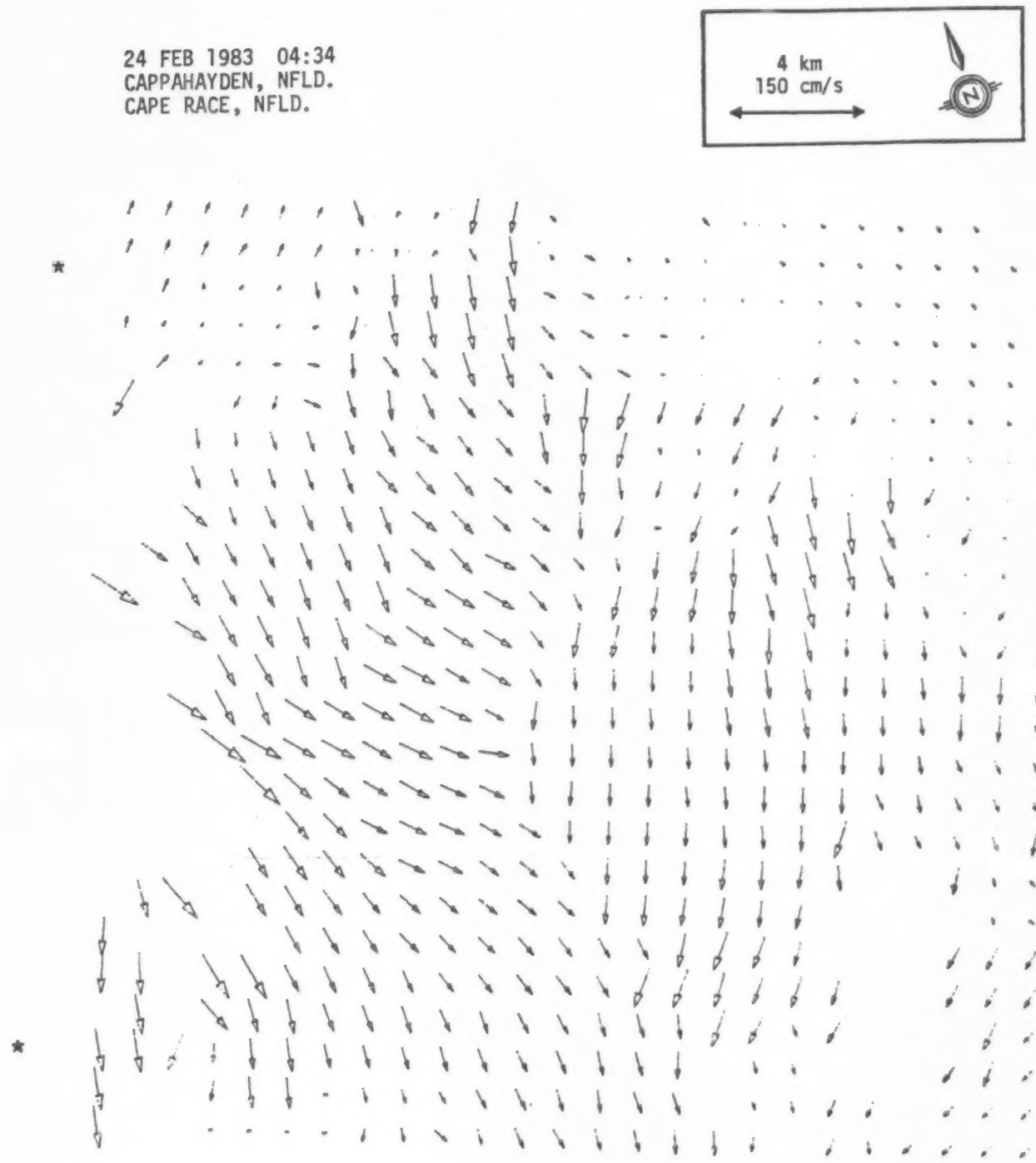


Figure 18 Same as Figure 15 but one hour later

9.0 CONCLUSIONS

All of the original objectives of this program have been met with little or no deviation from the original plan. A two station current mapping CODAR system has been implemented at C-CORE for evaluation purposes. It is anticipated that the results of this work will form the backbone of a new era of applied high technology to ocean surface research in Canada.

The hardware has been configured in such a manner as to permit an eventual service type role for both government and industry alike. Emphasis was placed on portability and speed of data reduction. It is now up to the oceanographic community in Canada to establish the acceptance criteria and empirical performance guidelines in future use.

Fisheries and Oceans Canada have played a key role in giving guidance throughout the technology transfer period. Researchers at the Bedford Institute of Oceanography are now beginning to focus on the question of performance limitations. Several experiments have been proposed over the next few years to address key issues of accuracy, resolution and dynamic range.

Close cooperation between American and West German researchers has been established and should continue to play an important role in total system development in the coming years. An International Workshop on Remote Sensing of Oceanic Variables Using HF Groundwave Radar is planned for the fall of 1983 at C-CORE. Representatives of at least seven major countries will present reports of their latest achievements encouraging discussion and dissemination of information in this area of

rapidly advancing technology.

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APPENDIX

CODAR Hardware Specifications

SPECIFICATIONS

COMPUTER

MANUFACTURER: DIGITAL EQUIPMENT CORP. (DEC)

MODEL #: LSI 11/23

SIZE: 13.2 cm H. x 48.3 cm W. x 57.8 cm D.

WEIGHT: 20 kg

POWER SUPPLY: 120 VAC, 60 Hz nominal

BACKPLANE: Q bus with 9 quad height slots and CD bus (H9273-A)

MOUNTING BOX: BA11-NC/NE

WORD LENGTH: 16 bits

MAX. MEMORY CAPACITY: 256 k bytes

CPU BOARD: DEC KDF11-AA with floating point option (KEF11-A)

MEMORY BOARD: CHRISLIN CI-1123 256 k byte (128 k x 18 bits)

SERIAL BOARD: DEC BDV11-AA (8 k bytes RAM + 2 serial lines) with bootstrap/diagnostic ROM option MXV11-A2

BAUD RATE: 150, 300, 1.2 k, 2.4 k, 9.6 k bits/sec.

CPU MICROCYCLE TIME: 300 n sec.

OPERATING SYSTEMS: RSX-11M and RSX-11S

COMPUTER TERMINAL

MANUFACTURER: DIGITAL EQUIPMENT CORP. (DEC)

MODEL #: VT100-AA

SIZE OF MONITOR: 36.83 cm H. x 45.72 cm W. x 36.20 cm D.

SIZE OF KEYBOARD: 8.89 cm H. x 45.72 cm W. x 20.32 cm D.

WEIGHT OF MONITOR: 15 kg

WEIGHT OF KEYBOARD: 2.0 kg

POWER SUPPLY: 120 VAC, 60 Hz nominal

INTERFACE: RS-232

BAUD RATE: 50 to 19,200 bits/sec.

CHARACTER FORMAT: 24 lines x 80 characters or 132 characters (VT1XX-AB)

CHARACTER RESOLUTION: 7 dots H. x 9 dots V.

SCREEN SIZE: 20.2 cm H. x 11.5 cm V.

OPTIONS: VT1XX-AB advanced video option

DISK DRIVE - WINCHESTER

MANUFACTURER: COMPUTER MEMORIES INC. (CMI)

MODEL #: CM5616

SIZE: 8.26 cm H. X 14.61 cm W. X 20.3 cm D.

WEIGHT: 2.3 kg

POWER SUPPLY: 5 VDC and 12 VDC regulated

CURRENT CONSUMPTION: 0.9 A @ 5 VDC and 2.2 A @ 12 VDC

FORMATTED MEMORY CAPACITY: 12.6 M bytes

DISK DIAMETER: 13.34 cm (5 1/4 in.)

NUMBER OF DISKS: 3/drive

MAX. TRANSFER RATE: 5M bits/sec.

CONTROLLER BOARD: DILOG DQ-604

DISK DRIVE - REMOVABLE

MANUFACTURER: DIGITAL EQUIPMENT CORP. (DEC)

MODEL #: RL/02

SIZE: 27 cm H. x 48 cm W. x 63.5 cm D.

WEIGHT: 33.75 kg

POWER SUPPLY: 120 VAC, 60 Hz nominal

FORMATTED MEMORY CAPACITY: 10.4 M bytes

DISK DIAMETER: 35.6 cm (14 in.)

NUMBER OF DISKS: 1 (removable)

MAX. TRANSFER RATE: 4.19 M bits/sec.

CONTROLLER BOARDS: DEC RLV11 (2 quad height boards using CD buss)

MAGNETIC TAPE DRIVE - CARTRIDGE

MANUFACTURER: ALLOY ENGINEERING CO. LTD.

MODEL #: LSI-30

SIZE: 11.48 cm H. x 21.77 cm W. x 35.79 cm D.

WEIGHT: 2.27 kg

POWER SUPPLY: 120 VAC, 60 Hz nominal

FORMATTED MEMORY CAPACITY: 20 M bytes with 450 ft. cartridge

TYPE: cartridge/serpintine/streamer

TRACKS: 4 (auto switching)

TAPE READ SPEED: 30 in./sec.

BIT DENSITY: 7600 bits/in.

TAPE WIDTH: 0.64 cm (1/4 in.)

CARTRIDGE TYPE: "3M" DC 300 XL (450 ft.)

CARTRIDGE SIZE: 1.65 cm H. x 15.24 cm W. x 10.16 cm D.

CONTROLLER BOARD: ALLOY LSI-30

MAGNETIC TAPE DRIVE - REEL TO REEL

MANUFACTURER: CYPHER DATA PRODUCTS

MODEL #: F880

SIZE: 22.23 cm H. x 43.18 cm W. x 55.88 cm D.

WEIGHT: 36.3 kg

POWER SUPPLY: 120 VAC, 60 Hz nominal

FORMATTED MEMORY CAPACITY: 10 M bytes with 17.78 cm reel (7 in.)

TYPE: reel to reel / non-serpintine / streamer / non-streamer

TRACKS: 9

TAPE READ SPEED: 25 in./sec.

BIT DENSITY: 1600 bits/in.

TAPE WIDTH: 1.27 cm (1/2 in.)

REEL SIZES: 17.78 cm to 26.67 cm (7 in. to 10 1/2 in.)

LOADING: automatic front end vacumn/manual

CONTROLLER BOARD: DILOG DQ-130

GRAPHICS DISPLAY BOARD

MANUFACTURER: SELANAR CORP.

MODEL #: PL100

SIZE: 1.3 cm H. x 25.4 cm W. x 25.4 cm D.

WEIGHT: 0.5 kg

LOCATION: VT100 terminal card cage

INTERFACE: serial to/from VT100 control board

BAUD RATE: 50 to 19,200 (set by VT100)

PLOT METHOD: vector and raster

SCREEN RESOLUTION: 1225 dots H. x 240 dots V.

ADDRESSABLE PLOT AREA: 65,536 dots H. x 65,536 dots V.

CHARACTER FORMAT: 20 lines x 122 characters

CHARACTER RESOLUTION: 7 dots H. x 7 dots V.

SCREEN SIZE: 20.2 cm H. x 11.5 cm V.

PLOTTER

MANUFACTURER: NICOLET ZETA CORP.

MODEL #: 1553

SIZE: 20.3 cm H. x 35.6 cm W. x 55.9 cm D.

WEIGHT: 20.5 kg

POWER SUPPLY: 120 VAC, 60 Hz nominal

INTERFACE: RS-232

BAUD RATE: 110 to 9600

BUFFER: 2048 bytes

MAX. PLOTTING SPEED: 35.9 cm/sec. diagonally. 25.4 cm/sec in axes

RESOLUTION: 63.5 m (0.0025 in)

PLOTTING AREA: 27.9 cm x 43.9 cm

PAPER: fan fold perforated 21.6 cm x 27.9 cm

OSCILLOSCOPE

MANUFACTURER: TEKTRONIX, INC.

MODEL: 465 B with DM44 option

SIZE: 19.1 cm H. x 32.8 cm W. x 46.0 cm D.

WEIGHT: 11.5 kg

POWER SUPPLY: 120 VAC, 60 Hz nominal

CHANNELS: 2

BANDWIDTH: DC to 100 MHz

TRANSCEIVER

MANUFACTURER: ERBTEC ENGINEERING INC. & CODAR TECHNOLOGY INC. (CTI)

MODEL #: 700

SIZE: 13.0 cm H. X 43.2 cm W. X 52.7 cm D.

WEIGHT: 20 kg

POWER SUPPLY: 120 VAC, 60 Hz nominal

TRANSMIT OUTPUT POWER: 10 dBm (into 50 Ω)

RECEIVE SENSITIVITY: -103 dBm (tangential)

PULSE WIDTH: 8, 16. 24, 32 μ sec.

PULSE REPETITION RATE: 1.953 kHz

INPUT/OUTPUT TRANSMIT FREQUENCY: 25.00 MHz to 25.95 MHz
(50 kHz steps)

DIGITAL INTERFACE: 12 bits data out (I & Q), 4 bits control

DIGITAL SAMPLING RATE: 125 kHz

ANALOG OUTPUT: $\pm$ 12V (I & Q)

OUTPUT MODE: baseband in-phase and quadrature (I & Q)

DYNAMIC RANGE: 100 dB nominal

OPERATION: coherent/monostatic/pulse/doppler

CONTROL: automatic only via. custom computer interface

CONTROL BOARD: CTI SPI board

OUTPUT SIGNAL CONNECTOR: UG-58A/u (type N female panel receptable)

TRANSMIT POWER AMPLIFIER

MANUFACTURER: ERBTEC ENGINEERING INC. & CODAR TECHNOLOGY INC. (CTI)

MODEL #: 600

SIZE: 19 cm H. X 43 cm W. X 38 cm D.

WEIGHT: 30 kg

POWER SUPPLY: 120 VAC, 60 Hz nominal

INPUT PEAK POWER: 10 dBm into 50 Ω

OUTPUT PEAK POWER: 70 dBm (10 k watts) into 50

PULSE WIDTH: 8 to 32 μ sec. nominal

TRANSMIT FREQUENCY: 25 to 35 MHz

OUTPUT BANDWIDTH: 250 kHz (with 8 μ sec. pulses)

PREAMP. DRIVE DEVICE: solid state (100 watts peak output)

INTERMEDIATE AMP. DRIVE DEVICE: ceramic triode tube

OUTPUT DRIVE DEVICE: 3 ceramic tubes in parallel

INPUT CONNECTOR: type BNC female panel receptacle

OUTPUT CONNECTOR: UG-58A/U (type N female panel receptacle)

MULTIPLEXER BOX

MANUFACTURER: INSTRUMAR LIMITED

SIZE: 8.9 cm H. x 15.9 cm W. x 15.9 cm D.

WEIGHT: 2.3 kg

POWER SUPPLY: 30 VDC & -24 VDC unregulated

CURRENT CONSUMPTION: 400 mA @ 30 VDC & 100 mA @ -24 VDC

ANTENNA INPUTS: 4

CONTROL: 3 digital lines (TTL)

GAIN: 10.7 dB $\pm$ 0.5 dB (20 to 30 MHz) (no filter)

OPTIONAL FILTER 3dB BANDWIDTH: 23.7 to 28.4 MHz

OPTIONAL FILTER INSERTION LOSS: 1.5 dB @ 25.4 MHz

FEED THRU ISOLATION: 55 dB minimum

BLANKING ISOLATION: 73 dB minimum

RF IMPEDANCE: 50 Ω nominal

MAX. RF INPUT POWER: +24 dBm maximum

RF OUTPUT POWER: +28 dBm (1 dB conpression)

SWITCHING RATE: 2 kHz nominal

INPUT SIGNAL CONNECTORS: UG-58A/U (4 type N female panel receptacle)

OUTPUT SIGNAL CONNECTORS: UG-58A/U (type N female panel receptacle)

MULTIPLEXER CABLES

MANUFACTURER: BELDEN

STOCK #: 8214

TYPE: 8/U

LENGTH: 2.95 M (1/4 wavelength @ 25.4 MHz trimmed to ± 0.2° phase zero at multiplexer junction. Matched to suit specific port.)

OUTSIDE DIAMETER: 1.029 cm

WEIGHT: 0.5 kg

AWG: 11 (bare copper)

STRANDING: 7 x 19 gauge

DIAMETER OF CONDUCTOR: 2.74 mm

INSULATION: cellular polyethylene

NOMINAL IMPEDANCE: 50 Ω

NOMINAL VELOCITY OF PROPAGATION: 78%

NOMINAL ATTENUATION: 1.5 dB/100 m. @ 25.4 MHz

INPUT CONNECTOR: UG-1185A/U (type N male plug)

OUTPUT CONNECTOR: Amphenol 82-326 (type N male angle plug)

TRANSMIT SIGNAL CABLE

MANUFACTUERER: BELDEN

STOCK #: 8214

TYPE: 8/U

LENGTH: 61 m (200 ft., nominal 1/2 λ multiples @ 25.4 MHz)

OUTSIDE DIAMETER: 1.029 cm

WEIGHT: 10.3 kg (on reel)

AWG: 11 (bare copper)

STRANDING: 7 x 19 gauge

DIAMETER OF CONDUCTOR: 2.74 mm

INSULATION: cellular polyethylene

NOMINAL IMPEDANCE: 50 Ω

NOMINAL VELOCITY OF PROPAGATION: 78%

NOMINAL ATTENUATION: 1.5 dB/100 m @ 25.4 MHz

INPUT CONNECTOR: UG-1185A/U (type N male plug)

OUTPUT CONNECTOR: UG-59B/U (type HN male plug)

RECEIVE SIGNAL CABLE

MANUFACTURER: BLEDEN

STOCK #: 8214

TYPE: 8/U

LENGTH: 61 m (200 ft., nominal 1/2 λ multiples @ 25.4 MHz)

OUTSIDE DIAMETER: 1.029 cm

WEIGHT: 10.3 kg (on reel)

AWG: 11 (bare copper)

STRANDING: 7 x 19 gauge

DIAMETER OF CONDUCTOR: 2.74 mm

INSULATION: cellular polyethylene

NOMINAL IMPEDANCE: 50 Ω

NOMINAL VELOCITY OF PROPAGATION: 78%

NOMINAL ATTENUATION: 1.5 dB/100 M @ 25.4 MHz

INPUT CONNECTOR: UG-1185A/U (type N male plug)

OUTPUT CONNECTOR: UG-1185A/U (type N male plug)

RECEIVE CONTROL CABLE

MANUFACTURER: BELDEN

STOCK #: 83396

TYPE: 4 conductor shielded cable (2 required per station)

LENGTH: 61 m (200 ft.)

OUTSIDE DIAMETER: 0.56 cm

AWG: 22 (tinned copper)

STRANDING: 7 x 30 gauge

INSULATION: FEP teflon

JACKET: silicone rubber

INPUT CONNECTOR: BENDIX PT06A-14-19S(SR) (PYGMY PT series straight plug)

OUTPUT CONNECTOR: AMPHENOL 97-3108B-18-1P (90° angle plug)

TRANSMIT ANTENNA

MANUFACTURER: INSTRUMAR LIMITED

TYPE: 3 ELEMENT YAGI (all aluminum construction)

VERTICAL ELEMENTS: 3 x 2.86 cm O.D. tubing

DIRECTOR HEIGHT: 2.37 m

DRIVER HEIGHT: 2.92 m

REFLECTOR HEIGHT: 3.14 m

DIRECTOR - DRIVER SPACING: 0.627 m

DRIVER - REFLECTOR SPACING: 2.70 m

3 dB BEAMWIDTH: 180°

IMPEDANCE: 50 Ω nominal

CONNECTOR: UG-560/U (type HN female panel receptacle)

RECEIVE ANTENNA ARRAY

MANUFACTURER: INSTRUMAR LIMITED

TYPE: PHASE MEASURING ARRAY

VERTICAL ELEMENTS: 4 x 2.84 m aluminum tubing (2.86 cm O.D.)

HORIZONTAL GROUND PLANE: 16 x 2.59 m steel whip antennas

ELEMENT SPACING: corners of square (359.2 cm x 359.2 cm)

IMPEDANCE: 50 Ω nominal

INPUT/OUTPUT CONNECTORS: UG-58 A/U (4 type N female panel receptacles)

TRANSPONDER

MANUFACTURER: ERBTEC ENGINEERING & CODAR TECHNOLOGY INC. (CTI)

MODEL #: 1100

SIZE: 2.0 cm H. X 12.7 cm W. X 30.5 cm D.

WEIGHT: 0.5 kg

POWER SUPPLY: 10 to 16 VDC unregulated

CURRENT CONSUMPTION: 100 mA @ 10 to 16 VDC

OUTPUT POWER: 33 dBm (2 watts) peak (fixed) into 50 Ω

SENSITIVITY: -85 dBm

INPUT PULSE WIDTH: 16 μ sec. nominal

OUTPUT PULSE WIDTH: 16 μ sec. nominal (fixed)

INPUT PULSE REPETITION RATE: 2 kHz nominal

OUTPUT PULSE REPETITION RATE: phase locked to input PRF

INPUT FREQUENCY: 25.400 MHz $\pm$ 1kHz minimum

OUTPUT FREQUENCY: phase locked to input frequency $\pm$ 1Hz modulation (fixed)

TANSPONDER DELAY: 25 μsec. nominal (fixed)

TEMPERATURE RANGE: -25°C to +20°C

SEARCH TIME: 2 sec. nominal

SLEEP TIME: 6. 14, 22, 30, 46 sec. strap selectable

ANTENNA: monostatic, 50 Ω nominal

RADIOMODEM

MANUFACTURER: GANDALF DATA COMMUNICATIONS LTD.

MODEL #: RADIOMODEM

SIZE: 6.1 cm H. x 33.5 cm W. x 29.5 cm D.

WEIGHT: 3.7 kg

POWER SUPPLY: 120 VAC, 60 Hz nominal

DATA SPEED: 300, 1200 & 2400 bits/sec. asynchronous
2400 & 3600 bits/sec. synchronous

OPERATION: data or voice mode (switch selectable)
full or half duplex
internal or external clock
analog loopback mode for self-test

DATA INTERFACE: EIA RS 232C

RADIO INTERFACE: custom modification

MOBILE RADIO

MANUFACTURER: MOTOROLA

MODEL #: SYNTOR T43SRA

SIZE: 6.4 cm H. x 29.2 cm W. x 43.2 cm D.

WEIGHT: 9.988 kg

POWER SUPPLY: 12 VDC regulated

FREQUENCY RANGE: 136 to 174 MHz

CHANNELS: up to 16 synthesized (32 channel optional)

MINIMUM RF POWER OUTPUT: 40 watts

MODULATION: 16F3 $\pm$ 5 kHz for 100% at 1 kHz (FM)

SENSITIVITY: 0.25 μ V (20 dB quieting EIA SINAD with pre-amp)

IMPEDANCE: 50 Ω nominal

VHF ANTENNA - TELEMETRY

MANUFACTURER: SINCLAIR

MODEL #: SRL-227

SIZE: 1.219 m H. x 1.905 m W. x 1.016 m D.

WEIGHT: 15 kg

TYPE: corner reflector

FREQUENCY RANGE: 132 to 150 MHz

NOMINAL GAIN: 7 dB

BANDWIDTH: 15% (1.5:1 VSWR)

POWER RATTING: 250 watts

POLARIZATION: vertical or horizontal

PATTERN: directional

IMPEDANCE: 50 Ω nominal

CONNECTOR: type N male